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ASR (OLAN SEAKEEPING TRIALS (AS BUILT CONFIGURATION)

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This report presents and discusses the results of seaworthiness trials conducted aboard the USS ORTOLAN (ASR-22) prior to the installation of a between hull forward foil. Ship motions, hull strains, and cross structure impacts are presented and comparisons are made between the ORTOLAN, the USNS HAYES (T-AGOR-16), and several monohulled ships. Current seaworthiness problems associated with the ASR Class are defined and discussed. Results indicate that while ship motions are not abnormal for a ship of this length, the frequency and intensity of cross structure impacts degrade the

seaworthiness of the craft to a point which is unsatisfactory. Seaworthiness problems associated with the ORTOLAN appear to be less severe than those of the "as built" HAYES and the addition of the foil should essentially eliminate these problems as it did for the HAYES. This foil should not break the water surface during any operational ship condition in state 5 seas or below. Strain measurements obtained indicate that although severe impacts occurred during the trial, the main structural integrity of the ship was not endangered. A second report discussing the post foil seaworthiness of the ORTOLAN will be published at the conclusion of presently scheduled post-foil trials.

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NOMENCLATURE

G, g	Gravitational acceleration
L	Ship length
M	Wave meter correction factor
P	Port
P-i	Pressure gauge i, i = 5, 6, 7, 8
PSI	Pounds per square inch (gauge)
S	Starboard
$S_a(\omega)$	Bow acceleration energy spectra
$S_x(\omega)$	Bow displacement energy spectra
$S_\theta(\omega)$	Pitch energy spectra
$S_\phi(\omega)$	Roll energy spectra
$S_\zeta(\omega)$	Wave energy spectra
U	Ship speed
$(Z_A)_{1/3}$	Single amplitude relative motion at Station $2\frac{1}{2}$
$(\theta_A)_{1/3}$	Single amplitude pitch angle
$(\phi_A)_{1/3}$	Single amplitude roll angle
λ	Wavelength
ζ_A	Single amplitude wave height
$(\tilde{\zeta}_w)_{1/3}$	Double amplitude significant wave height
ω	Circular wave frequency
ω_e	Circular encounter frequency
℄	Centerline

ABSTRACT

This report presents and discusses the results of seaworthiness trials conducted aboard the USS ORTOLAN (ASR-22) prior to the installation of a between hull forward foil. Ship motions, hull strains, and cross structure impacts are presented and comparisons are made between the ORTOLAN, the USNS HAYES (T-AGOR-16), and several monohulled ships. Current seaworthiness problems associated with the ASR Class are defined and discussed. Results indicate that while ship motions are not abnormal for a ship of this length, the frequency and intensity of cross structure impacts degrade the seaworthiness of the craft to a point which is unsatisfactory. Seaworthiness problems associated with the ORTOLAN appear to be less severe than those of the "as built" HAYES and the addition of the foil should essentially eliminate these problems as it did for the HAYES. This foil should not break the water surface during any operational ship condition in state 5 seas or below. Strain measurements obtained indicate that although severe impacts occurred during the trial, the main structural integrity of the ship was not endangered. A second report discussing the post foil seaworthiness of the ORTOLAN will be published at the conclusion of presently scheduled post-foil trials.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

A considerable number of model experiments have been conducted on the ASR Class catamaran at the Naval Ship Research and Development Center (NSRDC) in the past few years. They have been accomplished to determine the seaworthiness characteristics, bridging structure gross loadings, bridging structure slamming pressures, between hull wave patterns, and the resistance, powering

and stability characteristics. Experiments have also been conducted with the ASR catamaran as a "mothership" for the retrieval of a deep submersible rescue vehicle (DSRV) through the center well. In addition, an experimental investigation was carried out on a four point open sea moor of the ASR catamaran.

Currently, some negative experiences have been encountered with catamarans in heavy seas with bridging structure slamming. Model experiments with the USNS HAYES (T-AGOR-16) indicate that a foil near the bow, between the two hulls at the keel position, will significantly reduce the relative motion and the related slamming impact frequencies and pressures. Trials conducted by NSRDC with the HAYES confirmed that this installation of a between hull foil greatly reduces bridging structure slamming. A similar foil for installation aboard the USS ORTOLAN (ASR-22) has been designed. Prior to the installation of this foil, a pre-fix trial was conducted aboard the ORTOLAN to ascertain current seaworthiness characteristics and slamming pressures, i.e., to provide a baseline set of results against which the performance of the ORTOLAN with a foil may be compared. A second, post-foil modification trial will then determine the effectiveness of the foil. This report presents and discusses the data obtained during the pre-fix trial conducted aboard the ORTOLAN from 15 April to 25 April 1974.

TRIAL SITE AND TRIAL PROCEDURE

With the exception of Run 34, this trial was conducted in an area approximately 200 miles east of Assateague Island, Maryland. The ocean depth varied from 1000 to 2000 fathoms. Run 34 was recorded in an area east of Virginia Beach, Virginia in water approximately 170 fathoms in depth.

The trial procedure employed was as follows:

a. The trial director would request a particular heading and ship speed,

b. the bridge would inform the director when the ship course and steady speed had been obtained,

c. the trial director would notify the electronic technicians to commence collecting data,

d. the trial director would inform the bridge of the run completion and request the next trial condition.

Each trial run would commence when the ship had reached the steady speed requested for a particular heading. The run would continue for approximately 30 minutes during which time the ship maintained heading and speed with a minimum of rudder activity.

DATA COLLECTION

Measurements were recorded on two 14 channel magnetic tape recorders. Tape recorders and channel designations for trial measurements are given in Table 1. Transducer locations are presented in Table 2. Data collection is discussed in the following three sections.

WAVE HEIGHT

In order to correlate measured responses obtained during this pre-fix trial with model and future post-foil trial measurements, an accurate wave height measurement is required. Thus, four distinct measurements of wave height employing three different methods were made. These are:

a. Datawell wave buoy,

b. Tucker sea state meter - corrected and uncorrected,

c. visual observation by ship's force,

d. visual observation by NSRDC trial director.

The Datawell wave buoy obtains the seaway profile by double integrating the output of a stabilized accelerometer within the buoy while the buoy is afloat in the seaway. Wave height measurements using the wave buoy were made before and after each series of headings at a constant ship speed. These measurements were made at zero nominal speed and are referred to as wave runs. The Tucker sea state meter measures the height of the water surface on the ship's hull and adds this to the displacement of the hull relative to an imaginary reference surface defined by the calm waterline. The resultant height fluctuation of the water surface is therefore independent of the motions of the ship and represents wave height. Visual observations were made independently by ship's force and by the NSRDC trial director; that is, the observations were made independent of one another

as well as independent of the electronic wave measurements. A detailed investigation of the merits of each of the above methods is beyond the scope of this report; however, the comments contained in Table 3 are thought to be valid.

As noted in Table 3, a calibration correction factor, M, based on wave encounter frequency must be applied to the Tucker sea state meter measurement. This correction factor is necessary to account for the signal attenuation due to the depth of the pressure heads below the surface and for the attenuation due to the integrators and RC couplings within the device.[1] Figure 1 presents this correction curve as applicable to the installation used during this trial. Reference 1 states that the response of the sea state meter is best for low frequency wave encounters (correction factor ~ 1.0) becoming more uncertain for higher frequency encounters (correction factor >> 1.0). Hence Tucker wave height measurements are likely to be most accurate when ship speed is zero or the ship is proceeding in quartering or following seas.

SHIP MOTIONS

Ship motion measurements were recorded for roll, pitch, vertical acceleration at three locations, surge, sway, yaw, relative bow motion, and stern displacement. Surge and sway accelerations are not true surge and sway accelerations, but longitudinal and transverse accelerations, respectively, at their locations (see Table 2). True surge and sway accelerations are defined as the transverse and longitudinal accelerations at the ship center of gravity. Roll, pitch, and accelerations along the three ship axes were recorded at Frame 87½ using a modified Mark IV MOD 0 fire control stable platform. This device measured the true roll and pitch as well as true longitudinal, transverse and vertical accelerations at the transducer location. Yaw was recorded directly from the ship's gyro repeater. Bridge crane vertical acceleration and bow acceleration were unstabilized; that is, the transducer did not remain truly vertical but remained perpendicular to

1 "Manual for Calibrating, Installing and Operating the Ship-Borne Wave Recorder," National Institute of Oceanography (July 1955).

the longitudinal and transverse centerlines of the ship. The error thus induced by roll and pitch angles is small and will be neglected in this report.

IMPACT PRESSURES

Since impact frequencies of 100-200 Hz were expected, a recording system was chosen which would accurately record these frequencies. Actual impact frequencies, based on signal rise time, centered around 160 Hz. Shown in Figure 2 are the pressure gauge locations and proposed structural modifications.

No impact transducers were located on the forward faired edge of the cross structure since this area will be modified as shown during the installation of the foil. It is probable, however, that this area received more severe impacts than did any other section of the cross structure.

PRESENTATION OF DATA

Trial results are presented in two basic formats, tabular and spectral. All cognizant data collected during the trial are presented in tabular format. Data which are discussed in some detail are also presented in a spectral energy format.

Trial results are discussed in the following three sections.

WAVE HEIGHT

A summary of wave heights, true and relative courses, and ship speeds for all trial runs is presented in Table 4. Wave height values obtained from the wave buoy and the Tucker, after correction, are presented as significant values. Experience has indicated that wave heights noted visually by an observer will generally agree with the measured significant value. It is important to note that a significant value is defined to be the average of the highest one-third of the sample obtained.

The observed seaway is given as the vector addition of sea swell and sea waves; the swell being the regular or sinusoidal component, and the sea waves being the wind driven component. Wave heights as observed by the trial director and by ship's force agree well with the measured values in most cases, ship's force tending to agree with the wave buoy and the director with the Tucker. Agreement between the observers, however, as to swell height and sea height is not as good. In this case, the observed wave height could suffice to give a reasonable approximation of the sea, even though its composition may be disputed.

Figures 3, 4, and 5 present representative wave spectra recorded by the Tucker sea state meter, corrected and uncorrected, and by the Datawell wave buoy for Runs 13, 20, and 21, respectively. As noted in Table 3, a correction factor based on wave encounter frequency must be applied to the Tucker sea state meter measurement. Correlation between the corrected Tucker measurement and the Datawell wave buoy is good for Run 21 where the necessary correction is small. Run 13 also yields reasonable correlation between the corrected Tucker and the wave buoy even though the correction factor is relatively large. Run 20, however, shows much reduced energy in the 0.8 to 1.0 radian/second range for the Tucker when compared to the wave buoy. This decrease in energy shown by the Tucker is also evident over the same frequency range in the spectra for Run 13, but is not visible in Run 21. In general, the correlation between the Tucker and the wave buoy is good for wave heights above 6 feet. One exception is Run 20. This may be explained by noting that this run was made in darkness and seaway directionality could not be accurately determined. This may also explain the discrepancies found in Runs 1, 7, and 13 since the ship's head was directed toward the sea and not the swell.

SHIP MOTIONS

Ship motions, fore and aft longitudinal strain, and transverse midship strain are presented in Table 5. These values are presented as single amplitude significant values. Values indicated for longitudinal and vertical strain for all runs lie well within the design limits of the vessel. A

separate report presenting the analysis of these strains will be published in the future. Ship motions, as will be more thoroughly discussed, are not abnormal for a craft of this size. While roll and pitch motion in excess of 3 degrees single amplitude are detrimental to ship's work aboard any craft, changes in course and speed may be used to effect a reduction in these motions.

A low confidence level should be applied to the listed values of relative bow motion due to the spray present in the measurement area. The sonic device used is sensitive to heavy spray and may read it as a false target.

Spectral energy for roll in beam seas is presented in Figure 6 for a state 3 sea and in Figure 7 for a state 5 sea. Maximum rolling energy occurs at approximately 0.80 to 0.85 radians per second for all beam sea runs. This frequency corresponds to a roll period of 7.4 to 7.9 seconds and establishes the natural roll period of the ship to be approximately 7.6 to 7.7 seconds. In practical terms, this means that the ship in beam seas will have the greatest response to waves approximately 300 feet in length. The largest double amplitude value of roll recorded during the trial occurred during Run 24. The magnitude of this particular roll cycle was 20.7 degrees and its period was 7.7 seconds. Referring to Figure 7, we find that the spectral peak for roll energy during Run 24 lies at approximately 0.80 radian/seconds. This corresponds to a period of 7.85 seconds, closely agreeing with the period of the maximum double amplitude excursion. From the design viewpoint, it is to be noted that extreme roll angles will tend to occur with periods ranging from 7.4 to 7.9 seconds.

Wave spectra corresponding to head sea Runs 19, 22, and 30 are shown in Figure 8. It will be useful to refer to this figure when motions obtained during these runs are discussed. Note that these spectra are plotted versus frequency of encounter rather than wave frequency.

Spectral energy for pitch in head seas is presented in Figure 9 for a state 3 sea and in Figure 10 for a state 5 sea. We see that pitch, unlike roll, does not have its maximum values occurring within a discrete, relatively narrow range of frequencies for a given seaway. This is especially evident in Figure 9 where pitch angles were small, being less than 0.5

degrees significant single amplitude. When we address ourselves to significant values of pitch above ± 2.0 degrees (Figure 10) we find the spectra have a tendency to be more nearly single peaked. It is unfortunate, from a seaworthiness standpoint, that the pitch spectra for large values of pitch, although single peaked, are quite wide. For example, in Run 22 we see that a large amount of energy is contained in the frequency range from 0.7 to 1.1 radians per second. This indicates that the ship will respond actively in pitch to waves whose periods of encounter range from 6 to 9 seconds. The maximum double amplitude pitch excursion obtained during the trial occurred during Run 22. The magnitude of this pitch cycle was 12.8 degrees with a period of 7.0 seconds. Referring to Figure 10, we find that a 7.0 second period (0.90 rad/sec) falls within the range of maximum energy for pitch during Run 22. From a design standpoint then the extreme pitch motions will tend to have periods of from 6 to 9 seconds.

It should be noted that Run 22 is representative of an extreme condition; that is, the operators of the ORTOLAN expressed concern for the vessel during this run. This concern was based upon the intensity of the slams and the possibility of damage to the cross structure.

Bow acceleration, the parameter which determines bow velocity and displacement, is shown in Figure 11 and Runs 19, 22, and 30. Maximum bow accelerations tended to occur at 1.05 to 1.2 radian/seconds corresponding to periods of 5.2 to 6.0 seconds. Figure 12 presents the bow displacements corresponding to the bow accelerations shown in Figure 11. Since displacement is related to acceleration by frequency squared, the spectral peak of the displacement curve occurs at a lower frequency than the spectral peak of the acceleration curve. Hence, maximum displacements generally occur at lower frequencies than do maximum accelerations. The wave spectral peaks corresponding to Runs 19, 22, and 30, as shown in Figure 8, are indicated by the arrows on Figure 12. We see that maximum bow displacement tends to occur at the frequency of maximum energy in the seaway. These frequencies range from 0.76 to 1.09 radian/seconds corresponding to periods of 5.8 to 8.3 seconds.

Stern displacements for Runs 19, 22, and 30 are shown in Figure 13. Two observations are evident when we compare stern displacements to the

correspondi g r displacements. First, the bow displacements are greater in magnitud t n the stern displacements, and secondly, their peak frequencies are no n essarily the same. The fact that stern displacement was measured at a int about 17 feet to port of the ship's centerline does not appreciably af t the magnitude or phase of the data presented.

CROSS STRUCT MPACTS

The occu rence of slamming is dependent upon the magnitude and phase of the ship's vertical motions relative to the waves encountered. If the amplitude of the relative motion of the cross structure, where impacts are most likely, is less than the calm water clearance of the cross structure, recognizing sinkage, trim and bow wave effects, no impacts will occur. If, on the other hand, relative motion amplitude exceeds the calm water clearance, impacts will occur. The vertical motion of any point on the ship is primarily dependent on the magnitude and phase of its heave and pitch and the longitudinal distance of the point from the pitch axis, larger motions occurring furthest from the pitch axis. For this reason bow and stern impacts generally occur first. The intensity of the impact is dependent mainly on the relative velocity with which the ship and the sea meet, and the shape of the wave. Higher relative velocities and more massive waves yielding greater intensity.

Slamming pressures were measured at the four locations shown in Figure 2. Table 6 presents the number of occurrences, average and maximum pressures recorded, and the individual values of each occurrence for all impacts recorded during the trial. Note that no impacts were recorded in seas with a significant height of less than approximately 7 feet as measured by the wave buoy. Impacts were observed, however, at the mouth of the Delaware Bay while in transit to the trial location in an observed significant seaway of approximately 5 feet. This seaway consisted of regular swells with a periodicity of about 6 seconds. No measurements were obtained at this time.

Maximum impact pressures for the entire trial occurred during Run 22. A pressure of 105.8 pounds per square inch (PSI) was recorded on pressure

gauge number 5 (P-5), while a pressure of 68.7 PSI was recorded on P-8. Although no structural damage was evident at the conclusion of the trial, pressures of this magnitude are highly undesirable and are capable of producing structural damage to plates and stiffeners.

It should be noted that all recorded and observed impacts occurred on the cross structure. No impacts due to bow emergence and no bow emergence were observed while in transit or during the trial. Visual observations made continually throughout the trial indicated that the foil, if installed, would not have broken the water surface.

SELECTED MOTION COMPARISONS

Comparable full scale data for seakindliness comparisons can be closely approached by conducting side by side trials in the same seaway with the ships of interest. Full-scale comparisons made between data collected at different times and under varying conditions may be used only to point out trends and to show major differences in ship characteristics. Minor differences in seakeeping ability are generally masked by uncontrollable variables in the trial conditions, the most serious being variations in swell and sea composition.

This variation in swell and sea composition, i.e., the frequency and energy content of the seaway, makes full-scale comparisons difficult. An attempt has been made to point out tendencies of the ORTOLAN and HAYES based on available full-scale data. It should be realized that while one ship may appear superior in a given seaway, a change in seaway could indicate quite opposite conclusions. This report uses the information currently available and reaches conclusions based on that information. The application of these conclusions should take into account the basis of their formation.

Comparisons based on data obtained from model experiments and/or analytical predictions are more easily made since the parameters are much more closely controlled. In addition, they permit a range of investigation which cannot be matched by full-scale trials due to cost, time, and weather dependence. The accuracy of an analytical approach, based on model experiment

data, has been shown to be acceptable at low Froude numbers for both monohulled[2] and catamaran[3] vessels. The data presented in this report represents low Froude number conditions.

The following two sections present selected motion comparisons based on full-scale data and on analytical prediction techniques developed at NSRDC.

FULL-SCALE COMPARISONS

Roll and pitch angles for the ORTOLAN and three monohulled ships, see Table 7 for particulars, are given in Tables 8 and 9. Table 7 also presents the ship particulars for the HAYES. Wave heights listed in Table 8 represent observed (double amplitude) wave heights for the two trials, both observations being made by the same observer. For the five relative headings shown in Table 8, the ORTOLAN displays lower motions than the USS BOLSTER (ARS-38) in all but the following sea condition. The speed and wave height differences may account for the ORTOLAN motions being greater than those of the BOLSTER in the following sea condition.

Table 9 presents single amplitude significant pitch and roll angles for the ORTOLAN, the USNS GILLISS (T-AGOR-4) and the frigate O.W.S. WEATHER REPORTER. Note that ship speed for the ORTOLAN is lower than for the GILLISS or the WEATHER REPORTER. For the conditions shown, the ORTOLAN's roll and pitch are not significantly different than those for the monohulled ships. Based on these comparisons, the roll and pitch motions of the ORTOLAN are seen to be similar to those of monohulled ships of the same general length.

Although roll and pitch are comparable, the consequences of the induced motions are quite different. When the freeboard is exceeded on a monohulled ship, deck wetness and spray can occur. Exceeding the freeboard on a catamaran is usually equivalent to the beginning of cross structure impacts.

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2 Frank, W. and N. Salvesen, "The Frank Close-Fit Ship Motion Computer Program," NSRDC Report 3289 (June 1970).

3 Jones, H.D., "Catamaran Predictions in Regular Waves," NSRDC Report 3700 (Jan 1972).

These impacts may result in much increased hull girder loads, cross structure damage, and a generally uncomfortable condition for all aboard. Additionally, spray generated by the inboard hull edges and the forward edge of the cross structure will not clear itself of the ship, but instead can impair the vision of those in the pilot house by wetting the windows. During the ORTOLAN trial, spray was evident on the pilot house windows as early as Run 2 and the forecastle area was secured during Run 8 and several subsequent runs.

The increased beam of the catamaran, while providing the advantage of more usable deck area, also produces generally higher deck edge accelerations than would be found on a monohull of the same length and/or displacement. Run 34, which was recorded while the ORTOLAN was in a fore and aft starboard two point moor, is representative of an operational ship condition in which the bridge crane arms were extended and the bridge crane used. During all other runs, the bridge crane arm was secured. Ship's work proceeded normally during this run indicating that the increase in deck edge acceleration was not detrimental to ship's operations.

Figure 14 presents a comparison between the ORTOLAN and the HAYES for wave height and pitch spectra during similar runs at 5 and 12 knots. Note that both ships are catamarans and have approximately the same length (Table 7). Both Figure 14 and particulars given in Table 10 represent the HAYES prior to the installation of the between hull foil. Note also the scale changes within the figure. Referring to Figure 14, we see that the HAYES also tends to pitch with a frequency close to the frequency of maximum wave energy, as was discussed for the ORTOLAN. At 5 knots the magnitude of pitch was comparable for the two craft even though the ORTOLAN was operating in a higher seaway. At 12 knots the ORTOLAN recorded a significant pitch angle less than one half that recorded for the HAYES, with the ORTOLAN operating in a somewhat lower seaway.

Based on this data, we see that roll and pitch motions for the ORTOLAN are comparable to roll and pitch motions for monohulled ships of the same general length and that the ORTOLAN displays pitch characteristics that are comparable to, or better than, those of the HAYES prior to the installation of the foil.

ANALYTICAL PREDICTION COMPARISONS

Prior to the installation of the foil on the HAYES, reports of abnormally large ship motions prompted an analytical investigation which compared the HAYES to other craft of the same general length. Table 10 presents the particulars for the ships used in the investigation. The HAYES and the ORTOLAN (D) represent the craft as configured during the full-scale trials. The ORTOLAN (M) represents a modified design of the ASR class. The major differences between the ORTOLAN (D) and ORTOLAN (M) are in length and displacement. The differences between the three catamarans are in the hull particulars rather than in the lines. The USNS ROBERT D. CONRAD (AGOR-3) and USNS MELVILLE (AGOR-14) are monohulled craft used for oceanographic research with hull characteristics similar to the catamarans. The lines of these monohulls differ in that the MELVILLE has a slightly bulbous bow and flatter bottom aft. Ship "X" consists of a design using the MELVILLE lines and beam to draft ratio with a length and displacement equal to the HAYES.

Figure 15 presents predicted significant single amplitude pitch in state 5 and 6 head seas versus ship speed for the six craft discussed. We see that the HAYES does display relatively large pitch motions with the modified ORTOLAN only somewhat better. The "as built", or existing ORT N, is inferior to the three monohulls, except for Ship "X" above 12 knots. Note that Ship "X" is worse than the MELVILLE, indicating that a penalty is paid for increasing the beam, draft, and displacement. Note also that the ORTOLAN (D) has minimum pitching at zero speed.

Single amplitude significant relative motion at Station 2½ (approximately Frame 15 on the "as built" ORTOLAN) is shown in Figure 16 for state 5 and 6 head seas versus ship speed. Again the HAYES displays the worst motions with the ORTOLAN (M) only slightly better. The "as built" ORTOLAN (D) is superior to the HAYES and ORTOLAN (M), but inferior to the monohulled ships at all but the lowest ship speeds.

Figure 17, presenting the relative motion transfer function in head seas at 10 knots for Station 2½, shows that relative motion for the catamarans

is highly tuned to frequency* and $1\frac{1}{2}$ to $2\frac{1}{2}$ times greater in magnitude than for the monohulled ships. Again it is indicated that the HAYES displays the worst characteristics while the ORTOLAN (D and M) are inferior to the monohulls but superior to the HAYES. Most important is the fact that at resonance the catamarans will display very large relative motions. Hence, care should be used when describing these motions for a given sea state since the frequency distribution of wave energy contained within the sea state determines the magnitude of relative motion which may be expected. This analytical investigation was conducted using Pierson-Moskowitz sea spectra for fully risen seas. Comparisons between motions obtained here and motions obtained for seaways of different content should be made with caution

Summarizing the results of the foregoing comparisons, we have the following:

a. The "as built" HAYES displays a greater propensity to pitch and has greater relative bow motion than does the "as built" ORTOLAN.

b. Both the HAYES and ORTOLAN in the "as built" condition are more sensitive to the frequency of seaway energy than are monohulled ships of the same general length.

IMPACT COMPARISON

In comparing cross structure impacts, it must be noted that the calm water clearances of the cross structures for the ORTOLAN and the HAYES are not the same. Minimum clearance on the ORTOLAN was approximately $7\frac{1}{2}$ feet (uncorrected for sinkage, trim and bow wave effects) during the trial. Pressure gauges, as installed, were approximately 9 feet above the calm water surface (see Figure 2). The minimum clearance for the HAYES was approximately 10 feet (uncorrected for sinkage, trim and bow wave effects). This difference in clearance gives the HAYES an advantage in that the HAYES can undergo larger relative motions without incurring impacts. Figure 2

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*$\omega_e = 0.917(\lambda/L)^{-\frac{1}{2}} + 0.441(\lambda/L)^{-1}$ for Figure 17

shows that after modification the ORTOLAN will have a minimum clearance of about 9 feet and the clearance from the forward edge of the cross structure to Frame 19½ will be increased to approximately 11 feet. It is expected that this increase in clearance will result in fewer and less intense impacts on the forward cross structure.

The full-scale trials conducted aboard the HAYES included a rather detailed investigation of impact pressures occurring between Frame 16 and Frame 19 of the cross structure. Impacts occurring at Frame 25½ were recorded but have not been analyzed in detail. Figure 18 shows the location of the pressure gauges as installed aboard the HAYES. Table 11 presents impact data obtained during the HAYES pre-foil trial. Referring to Figure 2, we find that pressure gauge 5 of the ASR corresponds most closely with gauges 3.1 and 3.2 of the HAYES. While pressures obtained from gauges 3.1 and 3.2 are not presented due to currently incomplete analysis, the maximum value obtained in head seas, 9.5 foot significant wave height at 12 knots, was approximately 130 PSI. Studies of the HAYES data show that pressures obtained from gauge 1.1 - 1.8 are indicative of the pressures obtained for gauges 3.1 and 3.2. Comparing the 12 knot run found in Table 11 for the HAYES with Runs 19, 22, and 30 found in Table 6 for the ORTOLAN, we find the following information. The HAYES generally experienced higher maximum pressures, more impacts, and higher average impacts. If the ORTOLAN had run 12 knots during Run 22, impacts may have been greater than those of the HAYES. We note that when the HAYES increased from 12 to 16 knots, with a small increase in seaway, the maximum impact pressure went from 139 PSI to 205 PSI. The ORTOLAN running 11.5 knots in a nominal 8 foot head sea (Run 30) did not experience impacts of concern.

The occurrence of impacts on the after cross structure is also indicated by Table 6. Trials aboard the HAYES indicated that while after cross structure impacts did occur, their severity did not warrant a detailed investigation. In the analysis of the HAYES impact data, slams of 20 PSI or less were not regarded as significant. With respect to the after cross structure impacts recorded for ORTOLAN, 84 percent were less than 10 PSI while less than 4 percent were over 20 PSI.

Tables 6 and 11 indicate that both the ORTOLAN and the HAYES have cross structure impact problems in the "as built" condition which degrade the usefulness of the craft. Comparisons of pitch and relative motion at Station $2\frac{1}{2}$, as presented, indicate that the problem is comparable for the two ships even though the ORTOLAN has less cross structure clearance.

DISCUSSION OF TRIAL RESULTS AND COMPARISONS

The primary purpose of the trial was to establish a baseline set of data against which post-foil results could be compared. Tables 5 and 6 have presented sufficient "as built" seaworthiness characteristics to allow such a comparison to be made assuming equivalent data is obtained during the post-foil trial.

A secondary purpose was to characterize the current seaworthiness problems encountered by this class of ship. It is seen that cross structure slamming is the major problem since it interferes with the ability of the ship to transit during and/or between missions, and is capable of producing structural damage to the ship. Such structural damage has occurred on an earlier deployment. The major cause of this slamming is due to insufficient clearance and the large expanse of relatively flat surface which is exposed orthogonally to the sea in the form of the between hull cross structure. Figure 10 has shown that large values of pitch can occur across a relatively wide range of frequencies. Figure 12 has shown that bow displacement tends to occur at the frequency of maximum energy of the seaway, while Figure 17 has shown that relative motion near the forward edge of the cross structure is highly tuned, thus aggravating the problem. This means simply that cross structure slamming can, and will, occur (as shown in Table 6) in almost any seaway whose significant wave height is approximately 7 feet or above for head or bow ship headings relative to the waves. This slamming is attributable to the wide frequency response of pitch combined with the heave of the ship. Indeed, cross structure slamming will occur during much lower wave conditions if the encounter frequency is near the resonant frequency of relative motion

between cross structure and seaway. The experience at the mouth of the Delaware Bay is indicative of this type of slamming.

It is also found that while the HAYES AND ORTOLAN exhibit similar ship motion responses, the HAYES demonstrates a greater propensity to pitch and slam. The obvious question is: "Has the addition of a between hull foil improved the seaworthiness of the HAYES and, if so, will a similar foil improve the seaworthiness of the ORTOLAN?" This question may be answered in two parts; first, reports from the operators of the HAYES state that before installation of the foil a loss in operating time up to 50 percent was reported in moderate to heavy seas. Since the installation of the foil (approximately 7 months prior to the statement) no loss in operating time was experienced which could be attributed to the ship's performance or an inability to meet the mission requirements. The report goes on to state that the post-fix of the HAYES has yielded an oceanographic ship having better performance characteristics than any other U.S. oceanographic vessel. From this report it may be said that the operators of the HAYES feel the addition of the foil did significantly improve the seaworthiness of the HAYES.

Investigations[4] into the design of ocean catamarans indicate that the addition of the foil reduced the relative bow motion of the HAYES by about 30 percent resulting in a corresponding reduction in frequency and magnitude of cross structure slamming. This investigation also points out that rolling and corkscrew motions were also reduced, resulting in a significant improvement in the general seaworthiness of the HAYES. The second part of the question may be answered by noting that the HAYES and ORTOLAN display similar seaworthiness characteristics in the "as built" condition, with the ORTOLAN being generally more seaworthy, and that available data indicate that the ORTOLAN should respond similarly to the HAYES with the addition of a between hull foil.

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[4] Hadler, J.B. et al., "Ocean Catamaran Seakeeping Design, Based on the Experience of USNS HAYES," Presented at the Annual Meeting, Society of Naval Architects and Marine Engineers, November 14-16, 1974.

CONCLUSIONS

1. Cross structure wave impacts in the "as built" condition occur with a frequency and intensity that is detrimental to the usefulness of the ASR class. These impacts negatively affect the seaworthiness of the craft to a point which is unsatisfactory, i.e., damage plating and footings, cause crew discomfort, and force course and speed changes.
2. Ship motions are not abnormal for a ship of this length.
3. Wave impacts, pitch, and relative motion at Station 2½ appear to be less severe for the ORTOLAN than for the HAYES.
4. The ORTOLAN should respond to the addition of a between hull foil in a manner similar to that of the HAYES, thereby realizing a significant reduction in cross structure impacts and yielding acceptable seaworthiness characteristics.
5. The between hull foil should not break the water surface during any operational ship condition in state 5 seas or below.
6 Strain measurements obtained indicate that the main structural integrity of the ship was not endangered during the trial.

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TABLE 1 - TAPE RECORDER AND CHANNEL DESIGNATIONS
FOR TRIAL MEASUREMENTS

Tape Recorder A*	Tape Recorder B**
1. Tucker Sea State Meter	1. Vertical acceleration
2. Mode	2. Pressure gage P-5
3. Waverider Buoy	3. Tucker Sea State Meter
4. Bridge crane arm acceleration	4. Pressure gage P-6
5. Pitch angle	5. Pitch angle
6. Surge acceleration	6. Pressure gage P-7
7. Roll angle	7. Roll angle
8. Ship's speed log	8. Pressure gage P-8
9. Vertical acceleration	9. Bow acceleration
10. Sway acceleration	10. Mode
11. Ultrasonic (Relative Bow Motion)	11. Strain Bulkhead 37
12. Yaw angle	12. Strain Bulkhead 55
13. Bow acceleration	13. Strain Bulkhead 96
14. Tucker Sea State Meter (Duplication)	14. Waverider Buoy

* Ampex CP-100 Environmental Recorder, Double Bandwidth, 1 7/8 ips.

** Ampex CP-100 Environmental Recorder, Double Bandwidth, 3 3/4 ips.

TABLE 2 - TRIAL MEASUREMENT TRANSDUCER LOCATIONS

Measurement	Transducer Location(s)
Tucker Sea State Meter	Outboard port and starboard hulls, 8¼" forward of frame 53, 7'8" above baseline
Pressure Gauge P-5	Bottom plating of cross structure, 16" port of centerline, 7" aft of frame 23
Pressure Gauge P-6	Bottom plating of cross structure, 16" port of centerline, 11" forward of frame 45
Pressure Gauge P-7	Bottom plating of cross structure, 16" port of centerline, 7" aft of frame 87
Pressure Gauge P-8	Bottom plating of cross structure, 16" port of centerline, 9" aft of frame 108
Longitudinal Strain 37	Bulkhead 37, 8½' starboard of centerline, 6" below main deck in void 2-21-0-V
Longitudinal Strain 96	Bulkhead 96, 8½' starboard of centerline, 6" below main deck in void 2-84-0-V
Vertical Bending Strain 55	Outboard port and starboard sheet strake in passageways S-2-52-1-L and P-2-52-2-L
Bridge Crane Acceleration	52' ABL, frame 68 (frame 84, extended), aft port bridge crane arm. 43' port of centerline (75' port of centerline, extended)
Bow Acceleration	Centerline at tip of 7 ton bow boom, approximately frame 2½, 29½' above calm water surface

TABLE 2 - TRIAL MEASUREMENT TRANSDUCER LOCATIONS (Cont.)

Measurement	Transducer Location(s)
Ryan Radar Unit (Sonic)	As for bow acceleration
Yaw Angle (Ship's Course)	Ship's gyro, approximately S-4-33-0*
Pitch and Roll Angles, Sway and Surge Accelerations	Centerline at frame 87½, 14½" above main deck
Ship's Speed Log	P-5-27-1-T*
Vertical Acceleration	Centerline at frame 87½, 14½" above main deck
Waverider Buoy (Launched)	Buoy launched in seaway (measures sea state)
Waverider Buoy (Secured)	Port hull fantail, 5'9" forward of stern deck edge, 1'8" port of center well deck edge. (Measures relative stern motion)

* Standard naval nomenclature for compartment locations, P indicates port hull, S indicates starboard hull.

TABLE 3 - BRIEF COMPARISON OF THREE WAVE MEASUREMENT METHODS

Measurement Method	Advantages	Disadvantages
Datawell Wave Buoy	A. Performed well in accuracy trial conducted at NSRDC	A. Gives wave profile at a point other than ship's actual position.
	B. Does not require modifications to vessel	B. Requires deployment into seaway and attendant recovery
	C. After deployment measurement is independent of ship's movement	C. Possibility of loss if unattended
Tucker Sea State Meter	A. Gives wave profile at ship's position allowing wave by wave analysis vice statistical analysis	A. Accuracy dependent on wave frequency requiring a correction factor to be applied
	B. Ready for use anytime after warm-up period (self contained on vessel)	B. Requires thru hull penetration of vessel below waterline
		C. Works best at zero speed in head seas
Visual Observations	A. Height and relative direction of seaway established immediately	A. Subjective judgment of observer(s)

TABLE 4 - SUMMARY OF WAVE HEIGHTS, TRUE AND RELATIVE COURSES, AND SHIP SPEEDS

		Measured Sea Height			Observed Sea Condition								
					Director			Ship's Force					
Run No.	Run Duration (Minutes)	Buoy (Feet)	Tucker Uncorrected (Feet)	Tucker Corrected (Feet)	Swell (Feet)	Sea (Feet)	Total* (Feet)	Swell (Feet)	Sea (Feet)	Total* (Feet)	Ship Course (True)	Ship Speed (Knots)	Relative Course
1	21.3	2.9	1.1	1.7	3.0	1.0	3.2	2.0	2.0	2.6	355	-0.2	Wave run
2	29.1				3.0	1.0	3.2	2.0	2.0	2.8	300	7.2	Head seas
3	29.2				3.0	1.0	3.2	2.0	2.0	2.8	075	7.4	Port quartering seas
4	28.0				3.0	1.0	3.2	2.0	2.0	2.8	210	6.9	Starboard beam seas
5	27.2				3.0	2.0	3.6	2.0	2.0	2.8	345	7.4	Port bow seas
6	15.0				3.0	2.0	3.6	-	-	-	120	7.5	Following seas
7	28.0	4.2	2.6	3.2	3.5	1.5	3.8	3.0	1.0	3.2	320	-0.2	Wave run
8	28.0				4.0	1.5	4.3	4.0	2.0	4.5	280	11.8	Head seas
9	28.7				4.5	1.0	4.6	4.0	2.0	4.5	055	12.6	Port quartering seas
10	28.3				4.0	1.0	4.1	4.0	2.0	4.5	190	12.0	Starboard beam seas
11	29.5				3.5	1.5	3.8	4.0	3.0	5.0	325	12.0	Port bow seas
12	28.9				3.5	1.5	3.8	3.0	1.0	3.2	100	12.0	Following seas
13	29.2	3.9	1.7	3.0	3.5	1.0	3.6	4.0	2.0	4.5	290	-0.1	Wave run
14	29.0				3.5	1.5	3.8	4.0	2.0	4.5	290	2.6	Head seas
15	29.2				3.5	1.5	3.8	4.0	1.0	4.1	065	3.0	Port quartering seas
16	30.2				4.0	1.5	4.3	1.0	1.0	1.4	200	3.9	Starboard beam seas
17	28.8				4.5	2.5	5.1	*	*	*	335	1.0	Port bow seas
18	28.1				*	*	*	*	*	*	110	1.7	Starboard beam seas
19	26.0				*	*	*	*	*	*	030	6.3	Head seas
20	14.1	8.4	5.0	6.5	*	*	*	*	*	*	210	0.4	Wave run
21	25.5	11.5	9.7	11.1	9.0	2.5	9.3	5.0	5.0	7.1	020	0.0	Wave run
22	26.0				8.0	2.5	8.4	5.0	5.0	7.1	030	5.3	Head seas
23	25.3				7.0	1.5	7.2	7.0	3.0	7.6	165	5.5	Port quartering seas
24	29.2				6.5	1.5	6.7	5.0	5.0	7.1	300	5.0	Starboard beam seas
25	20.4				6.0	1.5	6.2	6.0	6.0	8.5	075	6.9	Port bow seas
26	35.0				6.5	2.0	6.8	6.0	2.0	6.3	210	7.0	Following seas
27	23.3	7.0	5.4	6.6	6.0	2.0	6.3	6.0	2.0	6.3	005	-0.1	Wave run
28	29.7				6.0	2.5	6.5	6.0	6.0	8.5	075	11.9	Port bow seas
29	29.9				6.0	2.5	6.5	6.0	5.0	7.8	300	12.5	Starboard beam seas
30	21.5				6.0	2.0	6.3	6.0	5.0	7.2	045	11.5	Head seas
31	28.8				6.0	2.5	6.5	6.0	3.0	6.7	210	12.0	Following seas
32	24.0				6.5	3.0	7.2	-	-	-	165	11.5	Port quartering seas
33	27.7	8.0	6.9	7.8	6.0	3.0	6.7	-	-	-	030	0.0	Wave run
34	29.2				6.0	2.5	6.5	-	-	-	082	0.1	Starboard beam seas

* Indicates darkness.

TABLE 5 - SUMMARY OF SHIP MOTIONS AND STRAINS (SINGLE AMPLITUDE SIGNIFICANT VALUES)

Run No.	Roll (Degrees)	Pitch (Degrees)	Vertical Acceleration (g's)	Surge (g's)	Sway (g's)	Crane Acceleration (g's)	Sonic Rdr. (Feet)	Strain Fr. 37 (KSI)	Strain Fr. 55 (KSI)	Strain Fr. 96 (KSI)	Bow Acceleration (g's)	Bow Displacement (Feet)	Stern Displacement (Feet)
1	0.81	0.46	0.024	0.004	0.010	0.024	2.71	0.049	0.100	0.121	0.029	1.10	-
2	0.58	0.30	0.013	0.004	0.009	0.018	-	0.107	0.108	0.114	0.023	0.92	0.74
3	1.13	0.50	0.042	0.004	0.015	0.030	-	0.208	0.090	0.180	0.047	1.50	1.20
4	0.75	0.58	0.039	0.005	0.019	0.035	-	0.221	0.108	0.173	0.059	1.74	1.46
5	0.42	0.25	0.017	0.005	0.012	0.019	-	0.122	0.110	0.129	0.022	0.80	0.71
6	0.52	0.48	0.026	0.005	0.010	0.025	-	0.135	0.107	0.128	0.053	1.60	1.08
7	0.71	0.60	0.042	0.007	0.015	0.040	-	0.189	0.138	0.159	0.043	1.79	-
8	0.47	0.30	0.023	0.006	0.012	0.023	-	0.119	0.154	0.133	0.032	0.98	0.89
9	1.15	0.44	0.023	0.005	0.018	0.030	-	0.257	0.125	0.213	0.041	1.35	1.18
10	1.06	0.60	0.047	0.008	0.030	0.043	-	0.352	0.149	0.333	0.064	1.72	1.75
11	0.53	0.25	0.024	0.005	0.018	0.026	0.73	0.205	0.161	0.212	0.025	0.83	0.72
12	0.50	0.45	0.025	0.005	0.011	0.024	1.25	0.151	0.124	0.160	0.050	1.49	0.91
13	0.91	0.58	0.046	0.006	0.012	0.040	2.66	0.186	0.162	0.215	0.049	1.46	-
14	0.75	0.46	0.028	0.006	0.011	0.027	1.78	0.175	0.153	0.168	0.040	1.28	1.15
15	1.21	0.52	0.027	0.005	0.015	0.032	2.26	0.216	0.160	0.215	0.047	1.56	1.18
16	0.65	0.68	0.045	0.007	0.019	0.033	3.80	0.227	0.179	0.246	0.070	1.94	1.54
17	0.90	0.68	0.061	0.009	0.019	0.048	1.35	0.240	0.240	0.284	0.065	1.60	1.83
18	3.30	1.31	0.065	0.009	0.059	0.103	0.95	0.892	0.339	0.711	0.131	3.38	2.57
19	0.82	2.00	0.135	0.025	0.021	0.104	1.78	0.405	0.442	0.372	0.229	5.65	4.22
20	5.95	2.41	0.067	0.028	0.053	0.107	1.31	1.064	0.512	0.789	0.140	6.24	-
21	4.31	3.82	0.107	0.031	0.035	0.089	-	0.591	0.726	0.564	0.198	10.08	-
22	2.96	4.52	0.140	0.033	0.035	0.125	-	0.533	0.761	0.418	0.341	12.53	8.38
23	4.57	2.21	0.063	0.025	0.038	0.093	-	0.724	0.637	0.528	0.080	6.26	5.60
24	7.00	1.85	0.088	0.015	0.054	0.125	-	0.903	0.603	0.911	0.154	6.18	5.24
25	5.20	3.65	0.121	0.026	0.048	0.175	-	0.586	0.535	0.566	0.305	10.47	7.32
26	2.15	1.75	0.033	0.023	0.022	0.046	-	0.368	0.484	0.355	0.054	4.55	3.91
27	3.10	2.35	0.070	0.017	0.026	0.068	-	0.437	0.456	0.408	0.142	6.42	-
28	3.20	2.80	0.140	0.025	0.040	0.170	-	0.461	0.464	0.427	0.298	9.21	5.39
29	4.20	1.38	0.077	0.016	0.045	0.085	-	0.486	0.299	0.595	0.133	4.81	3.33
30	2.14	2.43	0.132	0.025	0.032	0.134	-	0.359	0.395	0.332	0.265	7.01	4.45
31	1.46	1.45	0.056	0.022	0.019	0.032	-	0.297	0.392	0.285	0.039	4.06	3.17
32	3.98	1.05	0.106	0.013	0.033	0.084	-	0.477	0.259	0.499	0.065	3.62	3.62
33	2.48	3.16	0.181	0.026	0.022	0.065	-	0.346	0.451	0.301	0.161	8.41	-
34	1.24	1.14	-	0.012	0.034	0.068	-	-	-	-	0.128	3.49	-

TABLE 6 - SUMMARY OF CROSS STRUCTURE IMPACTS OCCURRING DURING PRE-FIX TRIAL

RUN 19 - HEAD SEAS, 6.3 KNOTS, LOW SEA STATE 5

P-5									
N = 10	5.7		18.0		5.7	2.1			
AVERAGE = 6.9	3.6		12.9		7.0				
MAXIMUM = 18.0	2.1		7.2		4.3				
P-6									
N = 1	14.3								
P-7	5.7		7.1						
N = 5	15.7								
AVERAGE = 7.2	5.8								
MAXIMUM = 15.7	2.0								
P-8	4.1	2.7	8.2	15.3	13.6	1.7	8.5	1.4	4.4
N = 35	3.4	10.5	6.1	6.8	1.0	3.4	6.8	11.6	3.4
AVERAGE = 6.3	2.0	17.7	1.0	14.3	14.3	1.4	6.8	1.0	9.5
MAXIMUM = 17.7	7.8	4.1	3.4	8.2	8.2	4.4	4.1	3.4	

TABLE 6 - CONTINUED

RUN 22 - HEAD SEAS, 5.3 KNOTS, HIGH SEA STATE 5

P-5								
N = 22	10.7	14.1	14.5	35.7	24.3	7.1	14.4	14.1
AVERAGE = 18.5	14.3	17.1	7.1	15.7	17.0	7.1	7.1	
MAXIMUM = 105.8	17.1	7.1	105.8	21.4	7.2	14.2	12.8	
P-6								
N = 1	5.7							
P-7								
N = 12	35.7	3.6	5.8	5.0				
AVERAGE = 7.9	3.6	5.6	3.6	8.6				
MAXIMUM = 35.7	7.1	5.8	4.3	8.6				
P-8								
N = 21	3.4	3.4	9.9	6.8	8.8	2.4	24.5	
AVERAGE = 10.5	6.1	68.7	4.1	5.0	3.4	10.2	23.8	
MAXIMUM = 68.7	1.0	7.5	5.1	3.5	5.1	14.3	2.7	

RUN 24 - BEAM SEAS, 5.0 KNOTS, MID SEA STATE 5

P-5	
N = 0	
P-6	
N = 0	
P-7	
N = 1	2.1
P-8	
N = 0	

TABLE 6 - CONTINUED

RUN 25 - BOW SEAS, 7.0 KNOTS, MID-SEA STATE 5

P-5				
N = 11	5.0	7.1	4.7	2.9
AVERAGE = 6.4	7.1	2.1	4.3	2.9
MAXIMUM = 14.3	12.9	7.4	14.3	
P-6				
N = 0				
P-7				
N = 1	15.7			
P-8				
N = 12	2.7	1.7	3.4	6.8
AVERAGE = 6.1	12.6	4.1	4.8	8.2
MAXIMUM = 13.6	13.6	4.8	4.1	6.8

TABLE 6 - CONTINUED

RUN 26 - FOLLOWING SEAS, 7.0 KNOTS, LOW-SEA STATE 5

P-5 N = 8 AVERAGE = 7.1 MAXIMUM = 9.8	7.1 5.7 8.6	7.1 3.6 7.1	8.6 9.3	
P-6 N = 1	7.9			
P-7 N = 0				
P-8 N = 10 AVERAGE = 3.7 MAXIMUM = 8.5	4.1 3.4 8.5	3.4 3.1 4.4	3.4 2.7 2.7	1.4

TABLE 6 - CONTINUED

RUN 29 - BEAM SEAS, 12.5 KNOTS, LOW-SEA STATE 5

P-5 N = 0									
P-6 N = 0									
P-7 N = 0									
P-8									
N = 25	3.4	27.2	2.7	10.2	3.4	4.1	4.1	2.7	3.7
AVERAGE = 5.4	2.7	3.1	2.4	6.8	4.8	4.4	2.0	4.4	
MAXIMUM = 27.2	3.4	13.6	3.1	3.4	4.4	6.5	3.1	5.8	

TABLE 6 - CONTINUED

RUN 30 - HEAD SEAS, 11.5 KNOTS, LOW SEA STATE 5

P-5 N = 3 AVERAGE = 6.7 MAXIMUM = 9.3	7.1 3.6 9.3					
P-6 N = 0						
P-7 N = 2 AVERAGE = 7.9 MAXIMUM = 8.6	8.6 7.1					
P-8 N = 17 AVERAGE = 4.5 MAXIMUM = 12.2	4.4 3.4 6.1	3.4 3.6 3.4	3.4 7.5 1.7	1.7 2.0 12.2	2.4 3.2 4.1	11.5 3.1

TABLE 7 - COMPARISON OF SHIP PARTICULARS FOR ORTOLAN, HAYES, BOLSTER, GILLISS, AND WEATHER REPORTER

		Catamarans		Monohulls		
		ORTOLAN	HAYES	BOLSTER	GILLISS	WEATHER REPORTER
Length Overall	(Feet)	251.0	246.4	213.5	208.3	225.0[1]
Beam Maximum	(Feet)	86.0[2]	75[3]	43.0	39.0	36.5
Draft	(Feet)	22.5	19.2	13.0	14.3	12.0
Displacement	(Tons)	4500	3180	1980	1350	1480
Roll Period	(Seconds)	7.6	7.4	9.4	9.2	-
Pitch Period	(Seconds)	7.5	5.9	5.8	-	-

[1] Length between perpendiculars.
[2] Single hull maximum beam = 26.0 feet.
[3] Single hull maximum beam = 24.0 feet.

TABLE 8 - COMPARISON BETWEEN THE ORTOLAN AND THE BOLSTER FOR SINGLE AMPLITUDE SIGNIFICANT ROLL AND PITCH

Relative Heading	Ship Speed ORTOLAN	Ship Speed BOLSTER	Wave Height ORTOLAN	Wave Height BOLSTER	Pitch ORTOLAN	Pitch BOLSTER	Roll ORTOLAN	Roll BOLSTER
Head	2.6	2.9	3.8	4.5	0.46	1.57	0.75	1.76
Bow	1.0	2.9	5.1	4.9	0.68	1.55	0.90	3.06
Beam	3.9	2.9	4.3	4.9	0.68	1.25	0.65	3.76
Quartering	3.0	2.9	3.8	4.5	0.52	1.16	1.21	3.83
Following	7.0	2.9	6.8	5.8	1.75	1.21	2.19	1.85

TABLE 9 - COMPARISON BETWEEN THE ORTOLAN, GILLISS AND THE O.W.S. WEATHER REPORTER FOR SINGLE AMPLITUDE SIGNIFICANT PITCH AND ROLL ANGLES IN HIGH STATE 5 SEAS

Relative Heading	Ship Speed ORTOLAN	Ship Speed GILLISS	Ship Speed WEATHER REPORTER	Pitch ORTOLAN	Pitch GILLISS	Pitch WEATHER REPORTER	Roll ORTOLAN	Roll GILLISS	Roll WEATHER REPORTER
Head	5.3	8	9.1	4.5	6.2	4.3	2.9	3.1	5.3
Bow	6.9	8	9.8	3.7	4.9	3.7	5.2	5.9	7.5
Beam	5.0	8	10.7	1.9	2.4	0.7	7.1	6.7	11.0

TABLE 10 - PARTICULARS OF SHIPS USED IN MAKING ANALYTICAL COMPARISONS

Particular	HAYES	ORTOLAN (D)	ORTOLAN (M)	MELVILLE	CONRAD	SHIP 'X'
Type of Ship	Catamaran			Monohull		
Length in Feet	220.0	240.2	230.0	220.7	197.0	220.0
Beam (Single Hull) in Feet	24.0	26.0	26.0	46.0	37.0	54.0
Beam (Overall) in Feet	75.0	86.0	86.0	46.0	37.0	54.0
Draft (Station 10) in Feet	18.9	22.4	19.0	15.4	14.6	21.2
Displacement in Long Tons	3124	44[illegible]3	3540	2074	1313	3124
Hull Separation in Feet	27.0	34.0	34.0	--	--	--
CG Aft of FP in Feet	111.2	122.7	113.9	111.1	102.1	114.0
Longitudinal Radius of Gyration	0.25L	0.25L	0.25L	0.24L	0.24L	0.24L
Block Coefficient	0.54	0.60	0.57	0.46	0.44	0.44
Beam/Draft	1.27	1.16	1.37	3.00	2.54	2.54
Length/Beam	9.17	9.24	8.85	4.80	5.32	4.07
Length/Beam (Overall)	2.93	2.79	2.67	4.80	5.32	4.07

TABLE 11 - AGOR-16 PEAK PRESSURES FOR WAVE IMPACTS AT BOTTOM OF FORWARD CROSS STRUCTURE

12 Knots in a 9.5 Foot Significant Head Sea (30 Min.)

Pressure Gauge	Number of Impacts	Impact Pressures - PSI					
		Maximum	Minimum	Range	Mean	Standard Deviation	Maximum Mean
P 1.1	31	89	8	81	21	15	4.2
P 1.2	51	139	8	131	34	24	4.1
P 1.3	54	83	10	73	28	15	3.0
P 1.4	57	88	8	80	32	17	2.9
P 1.5	50	89	10	79	25	16	3.6
P 1.6	46	98	8	90	30	21	3.3
P 1.7	49	92	10	82	29	17	3.2
P 1.8	46	138	12	126	34	28	4.1
Average:	48	102	9.3	92.8	28.9	19.1	3.5

16 Knots in a 10.3 Foot Significant Head Sea (13 Min.)

Pressure Gauge	Number of Impacts	Maximum	Minimum	Range	Mean	Standard Deviation	Maximum Mean
P 1.1	25	47	12	35	23	9	2.0
P 1.2	28	139	12	127	35	25	4.0
P 1.3	27	147	8	139	34	30	4.3
P 1.4	24	144	10	134	32	29	4.5
P 1.5	26	84	8	76	31	20	2.7
P 1.6	21	62	9	53	26	19	2.4
P 1.7	24	205	10	195	39	40	5.3
P 1.8	22	114	10	104	34	5	3.4
Average:	25	118	10	107.9	31.8	22.1	3.6

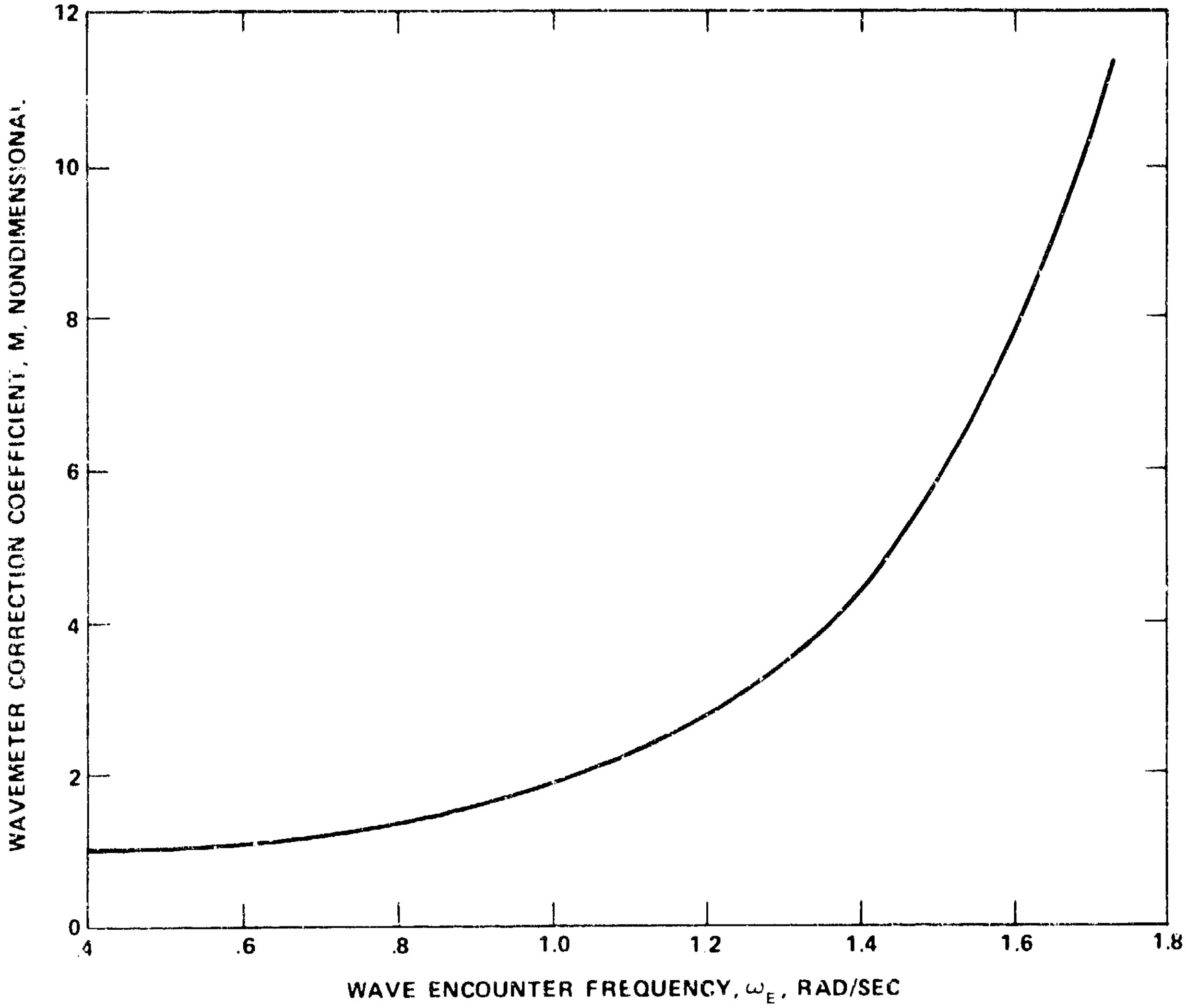

Figure 1 - Correction Coefficient Applied to Power Spectra Obtained from the TUCKER Sea State Meter

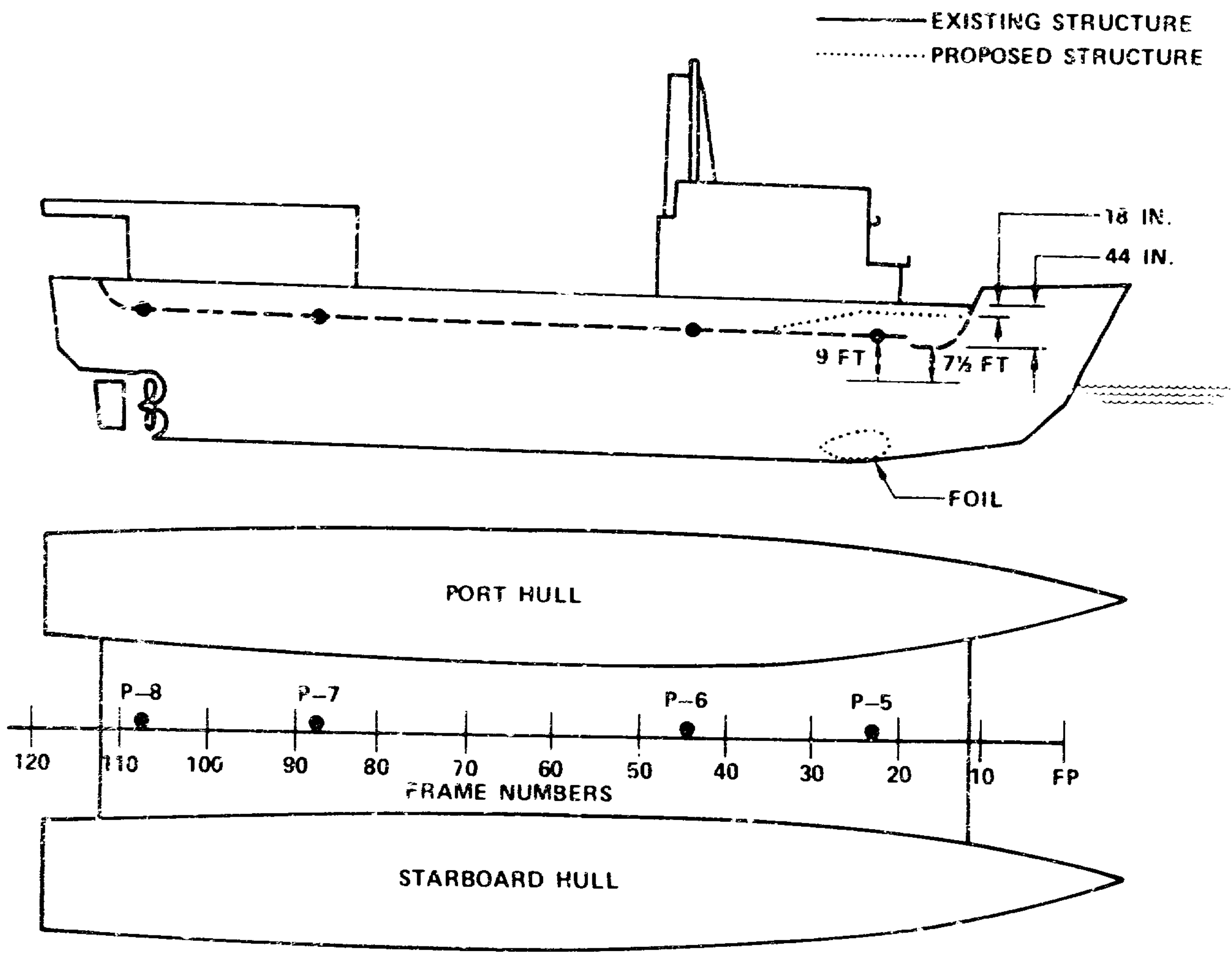

Figure 2 - Sketch of ORTOLAN Showing Pressure Gauge Locations and Proposed Modifications

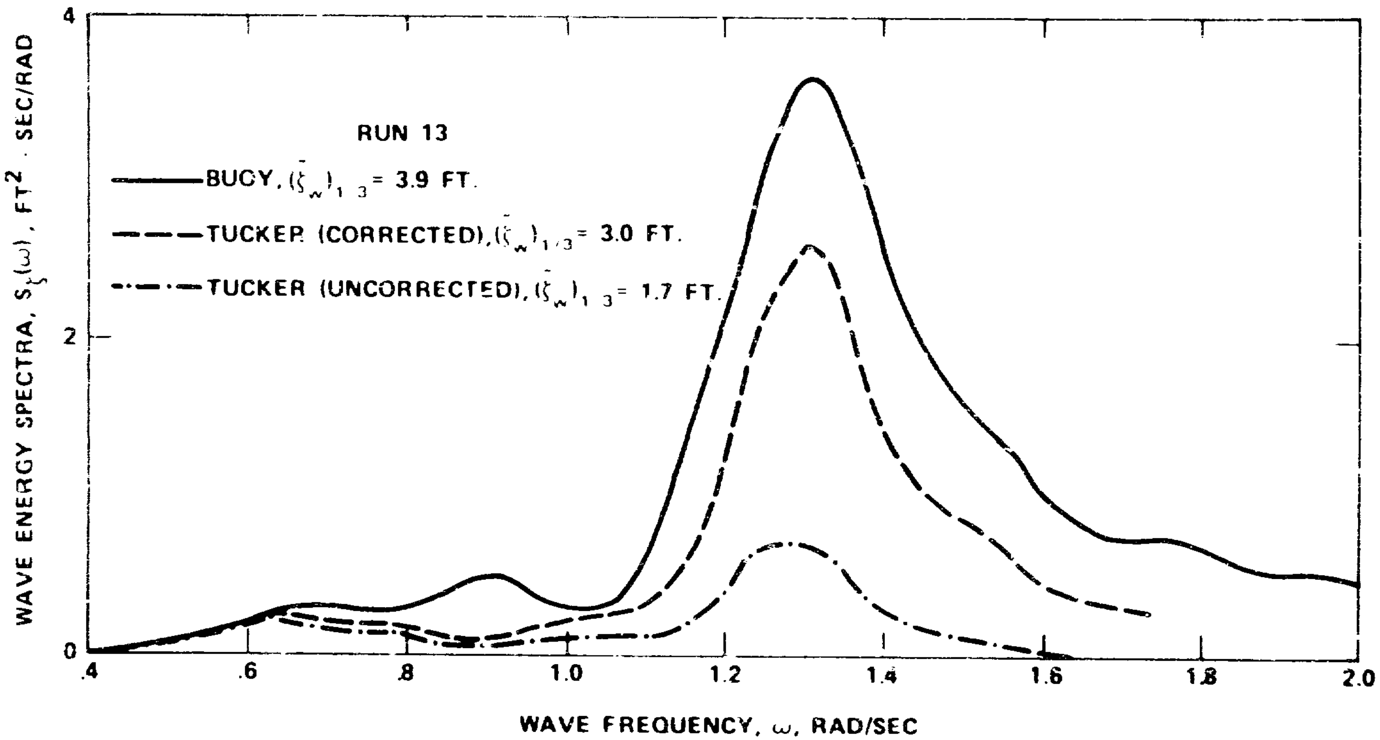

Figure 3 · Comparison Between the Wave Spectra Obtained from the Tucker Sea State Meter and the Wave Buoy for Run 13

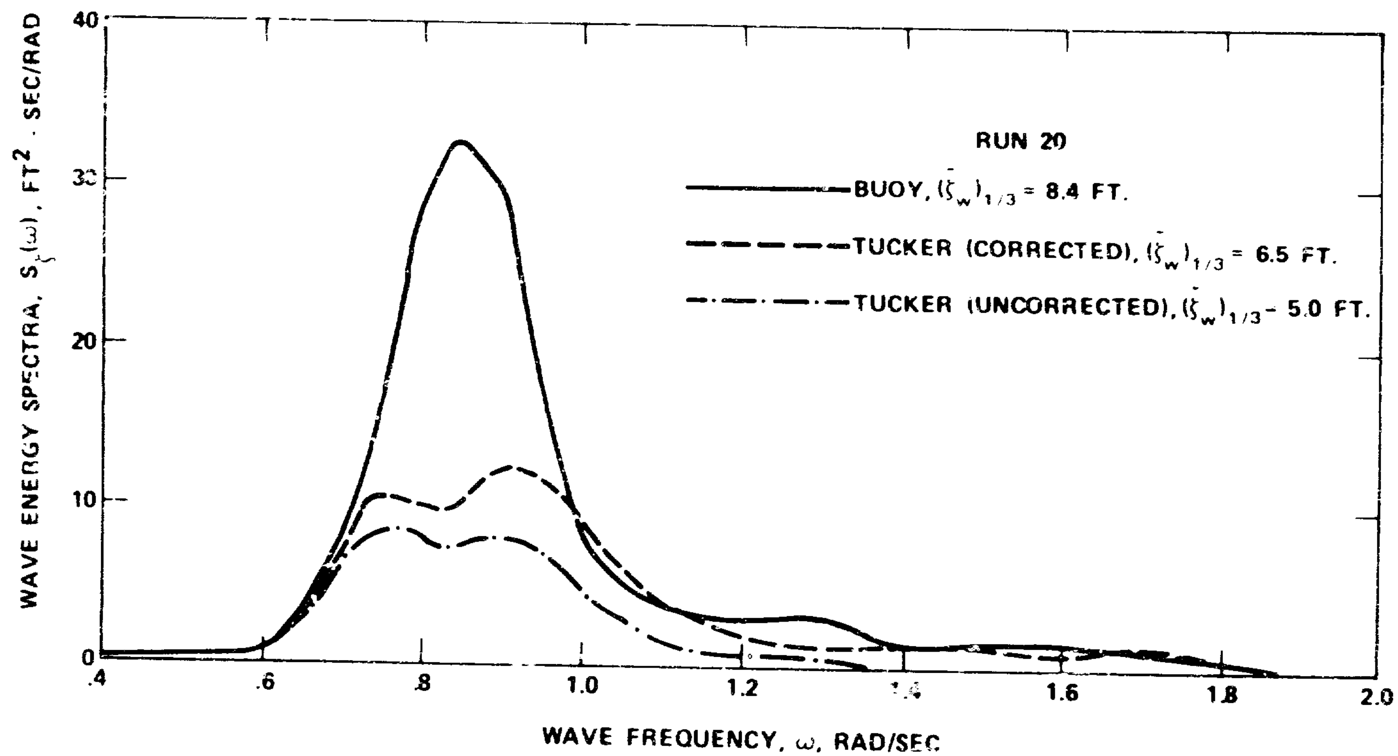

Figure 4 - Comparison Between the Wave Spectra Obtained from the Tucker Sea State Meter and the Wave Buoy for Run 20

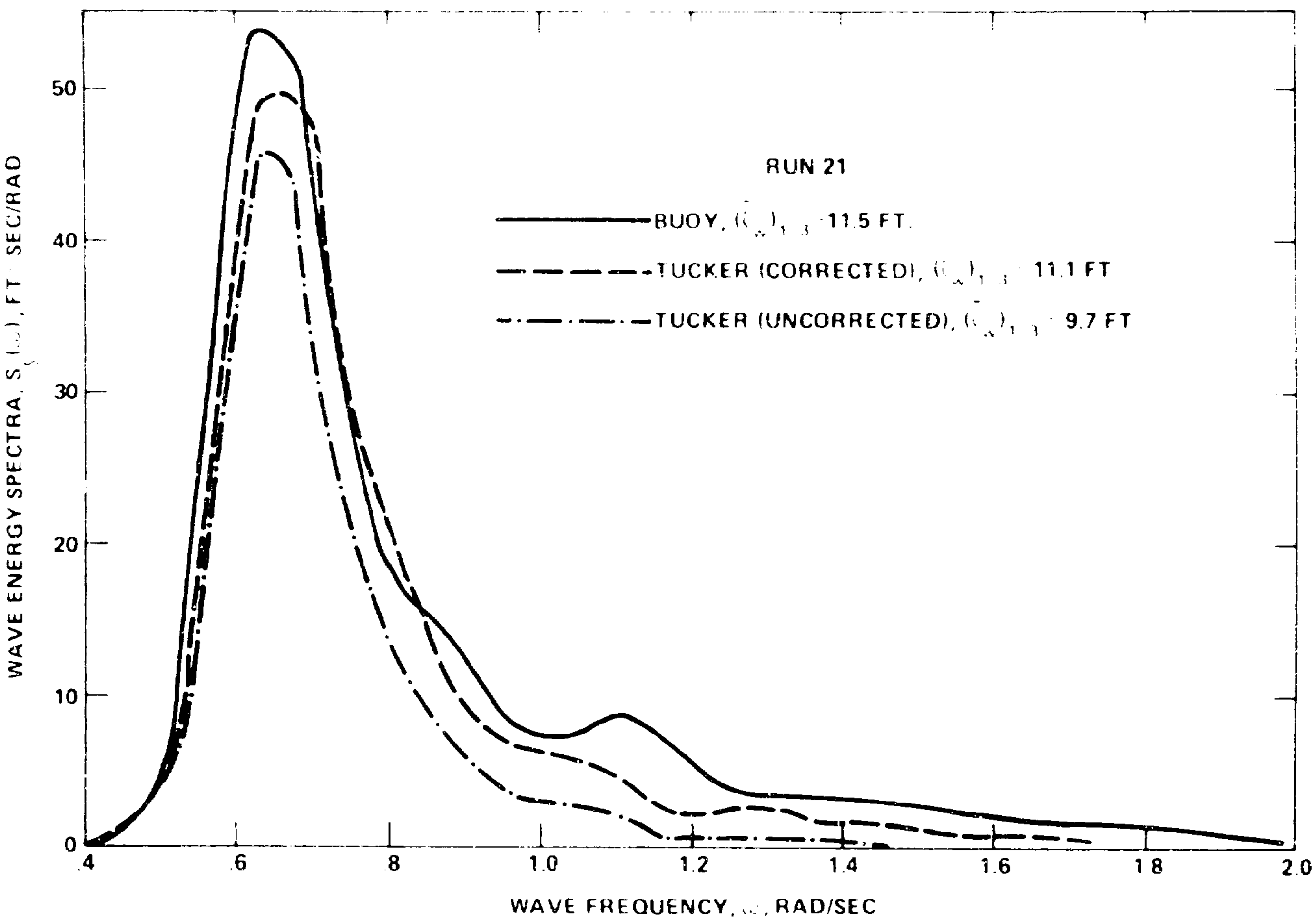

Figure 5 Comparison Between the Wave Spectra Obtained from the Tucker Sea State Meter and the Wave Buoy for Run 21

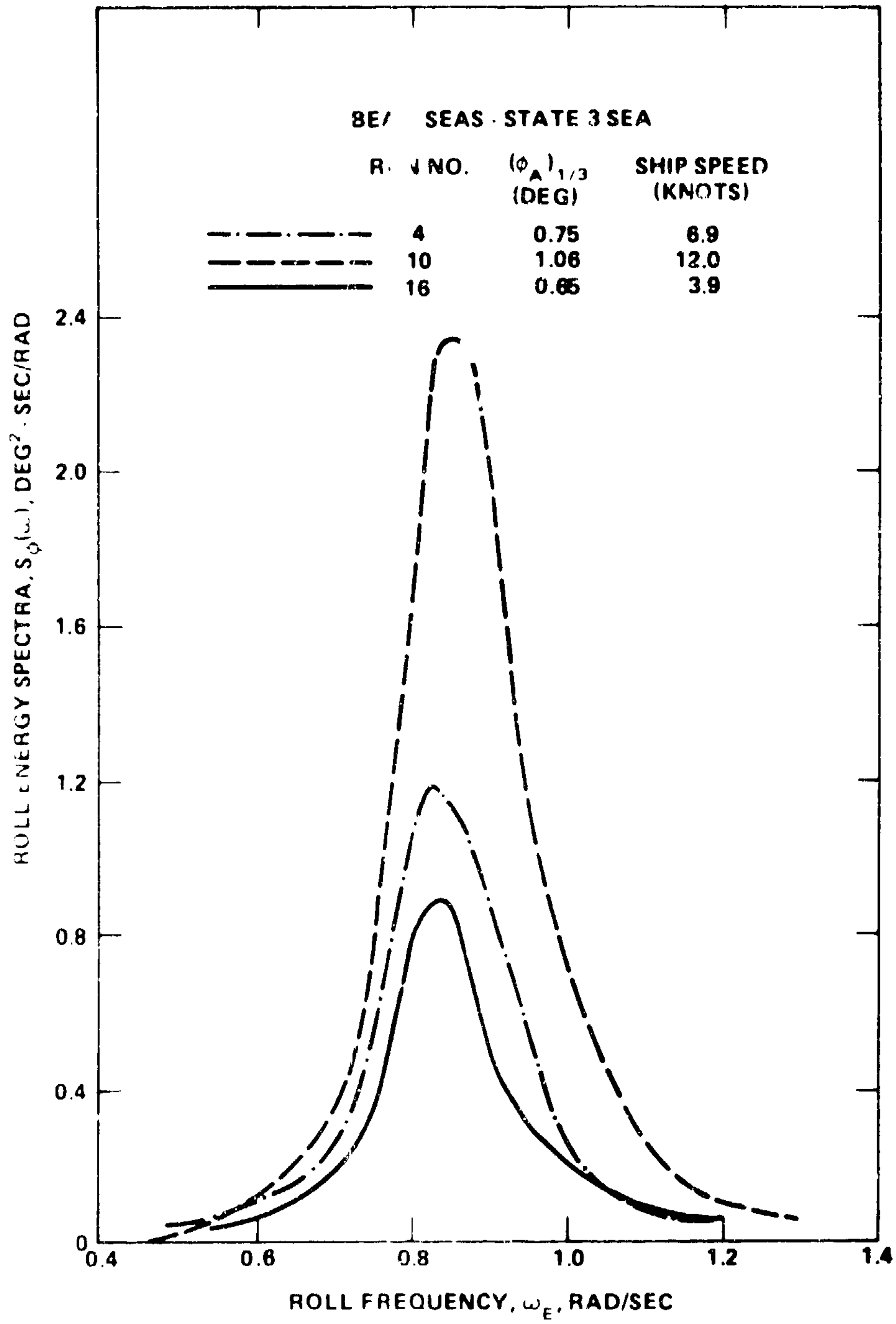

Figure 6 - Spectral Energy for Roll in Beam Seas, State 3 Sea, at 3.9, 6.9 and 12.0 Knots

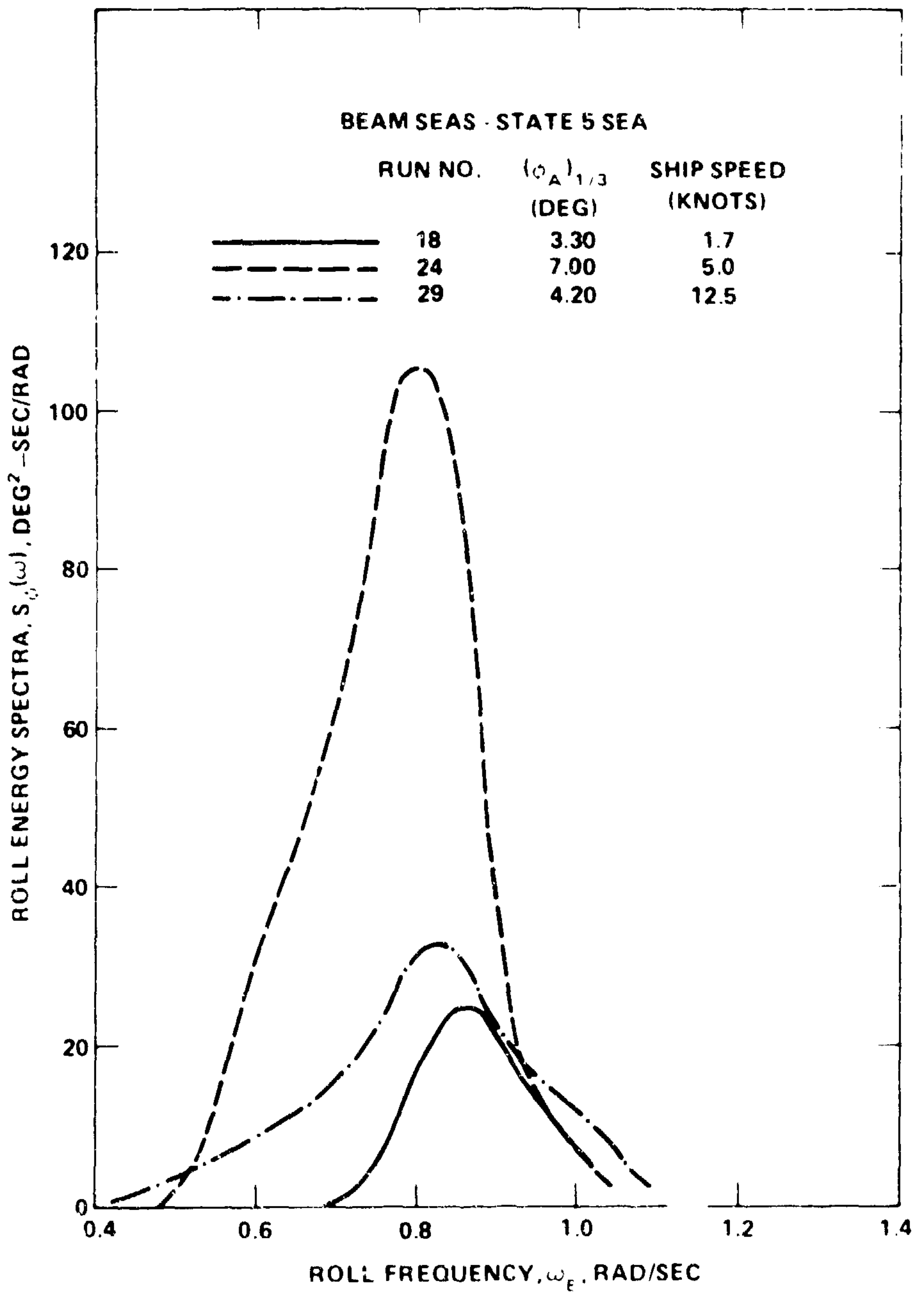

Figure 7 - Spectral Energy for Roll in Beam Seas, State 5 Sea, at 1.7, 5.0, and 12.5 Knots

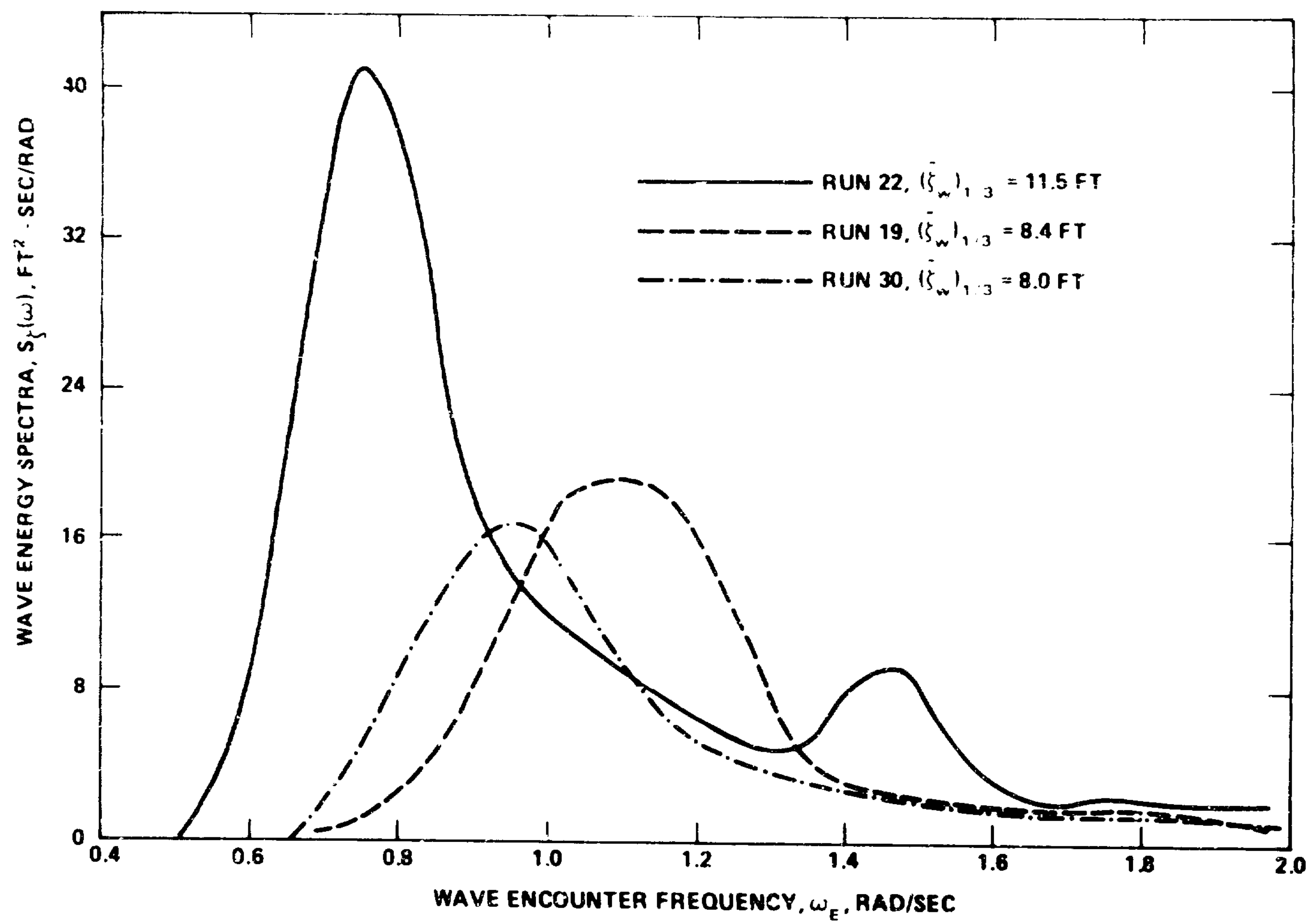

Figure 8 - Wave Spectra Corresponding to Runs 19, 22, and 30

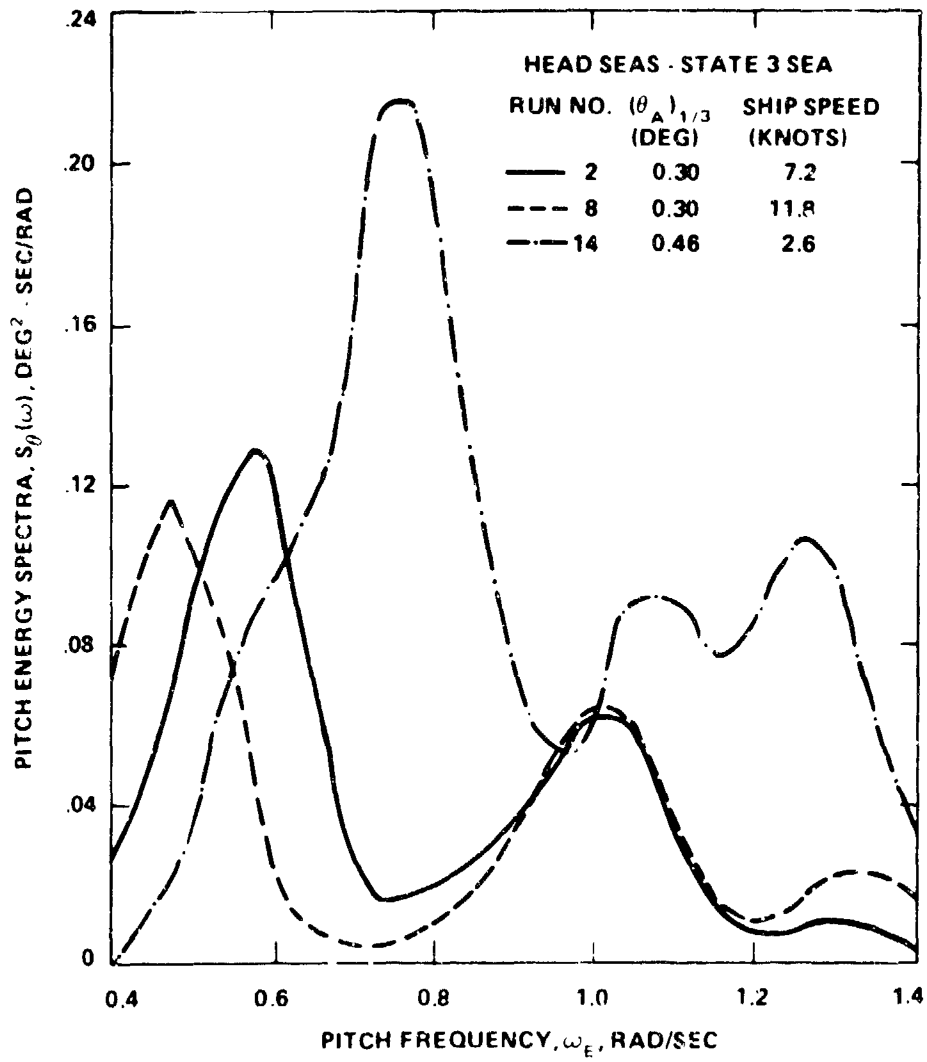

Figure 9 - Spectral Energy for Pitch in Head Seas, State 3 Sea, at 2.6, 7.2, and 11.8 Knots

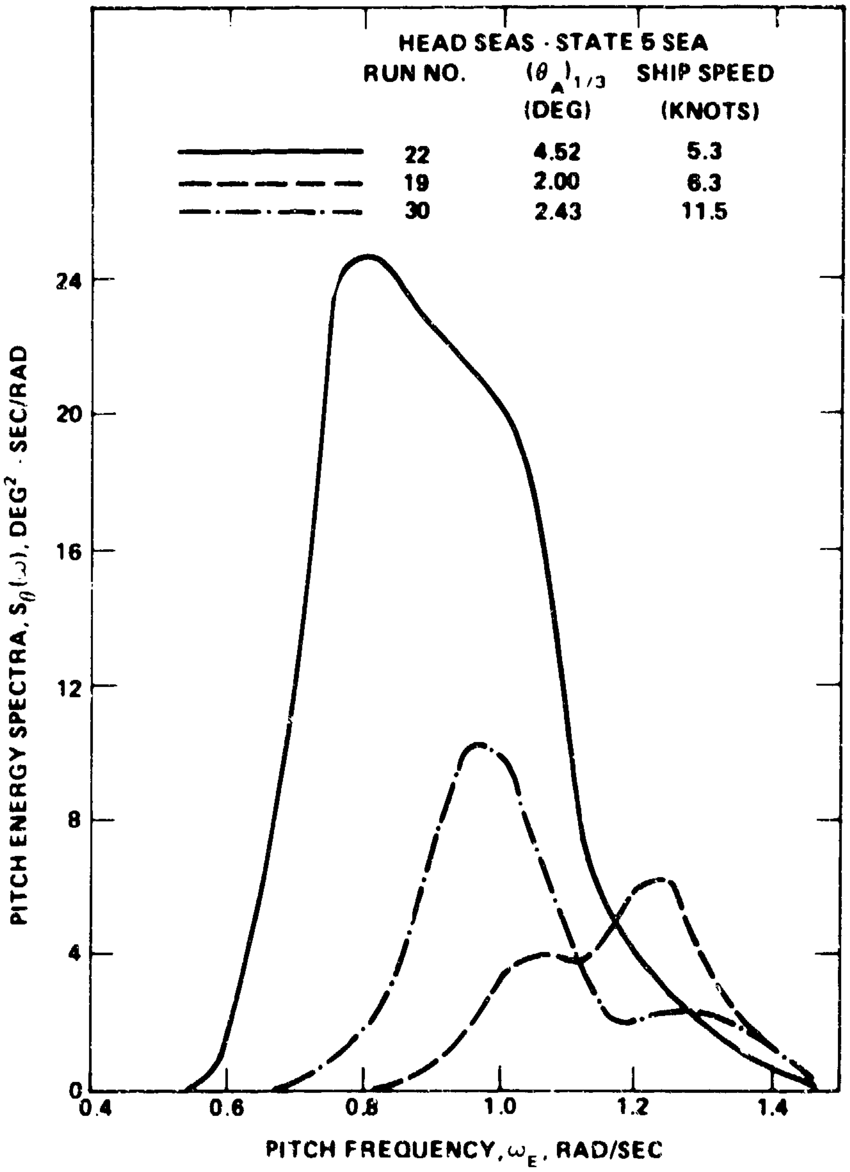

Figure 10 · Spectral Energy for Pitch in Head Seas, for State 5 Sea, at 5.3, 6.3, 11.5 Knots

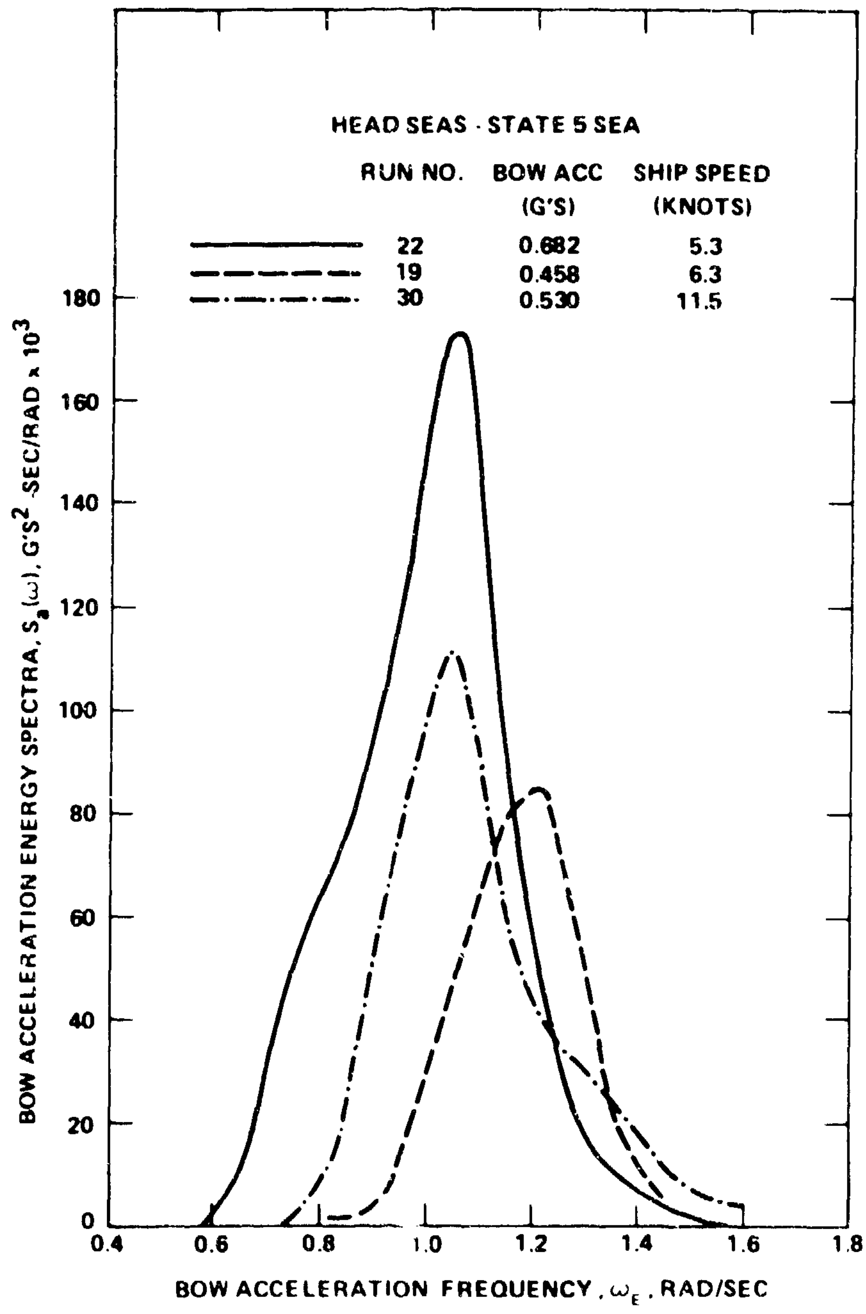

Figure 11 - Spectral Energy for Bow Acceleration in Head Seas, State 5 Sea, at 5.3, 6.3, and 11.5 Knots

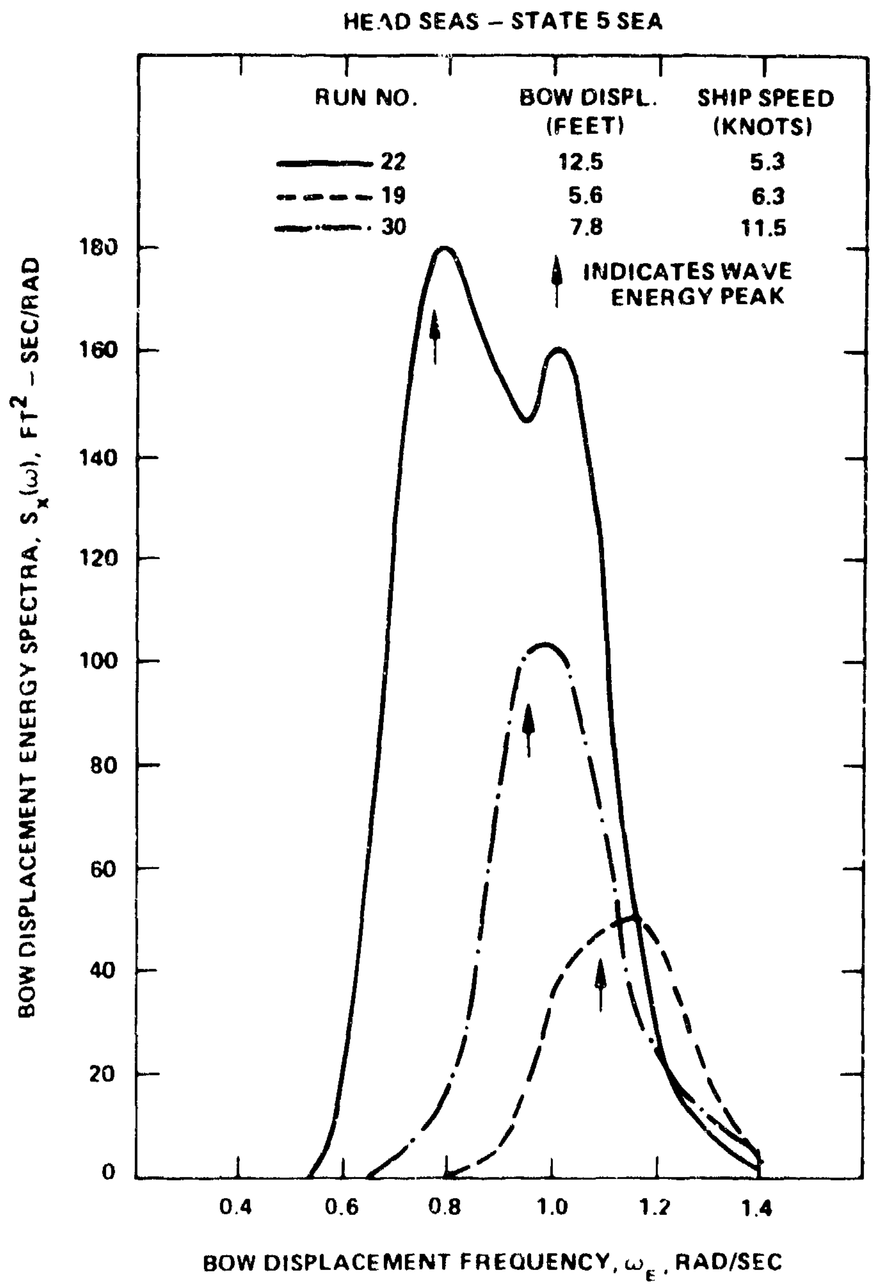

Figure 12 -- Spectral Energy for Bow Displacement in Head Seas, State 5 Sea, at 5.3, 6.3, and 11.5 Knots

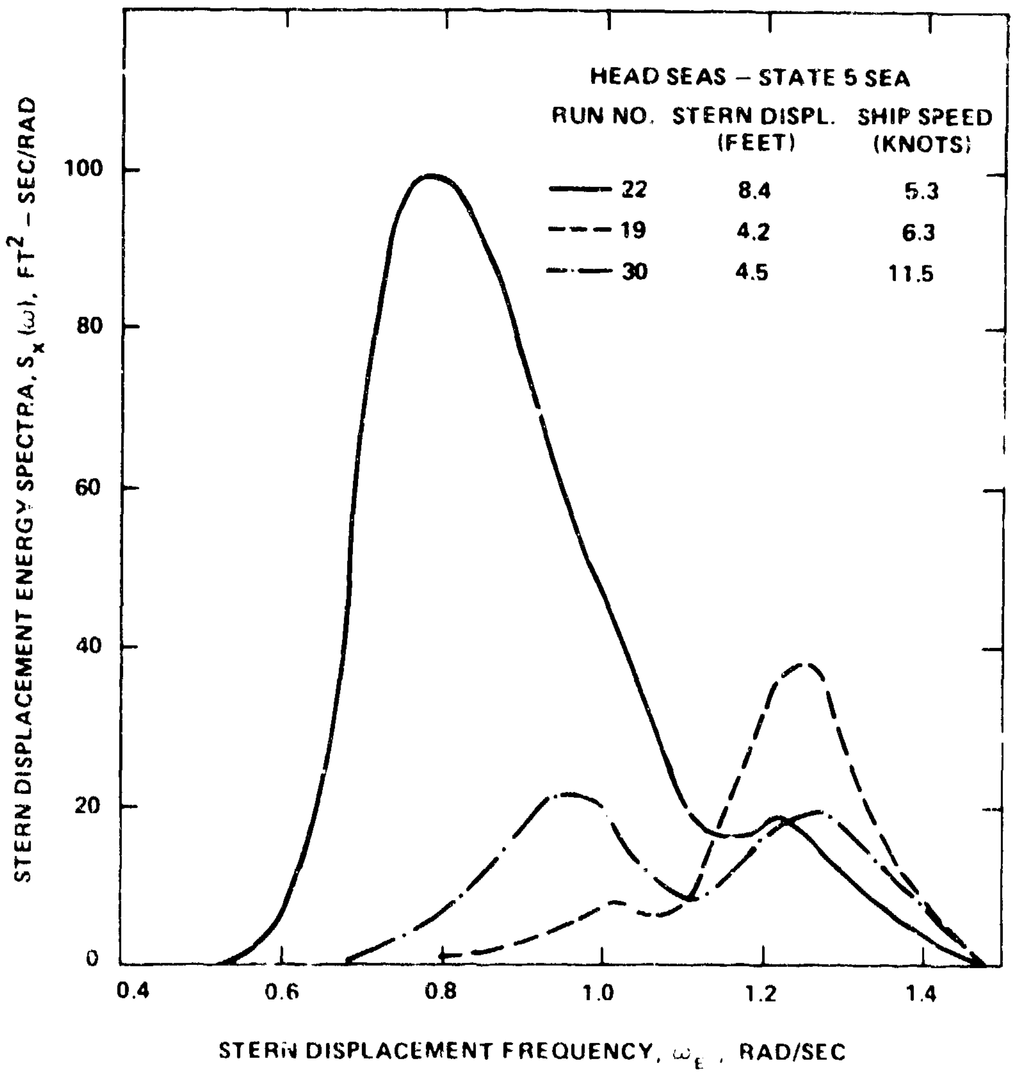

Figure 13 – Spectral Energy for Stern Displacement in Head Seas, State 5 Sea, at 5.3, 6.3, and 11.5 Knots

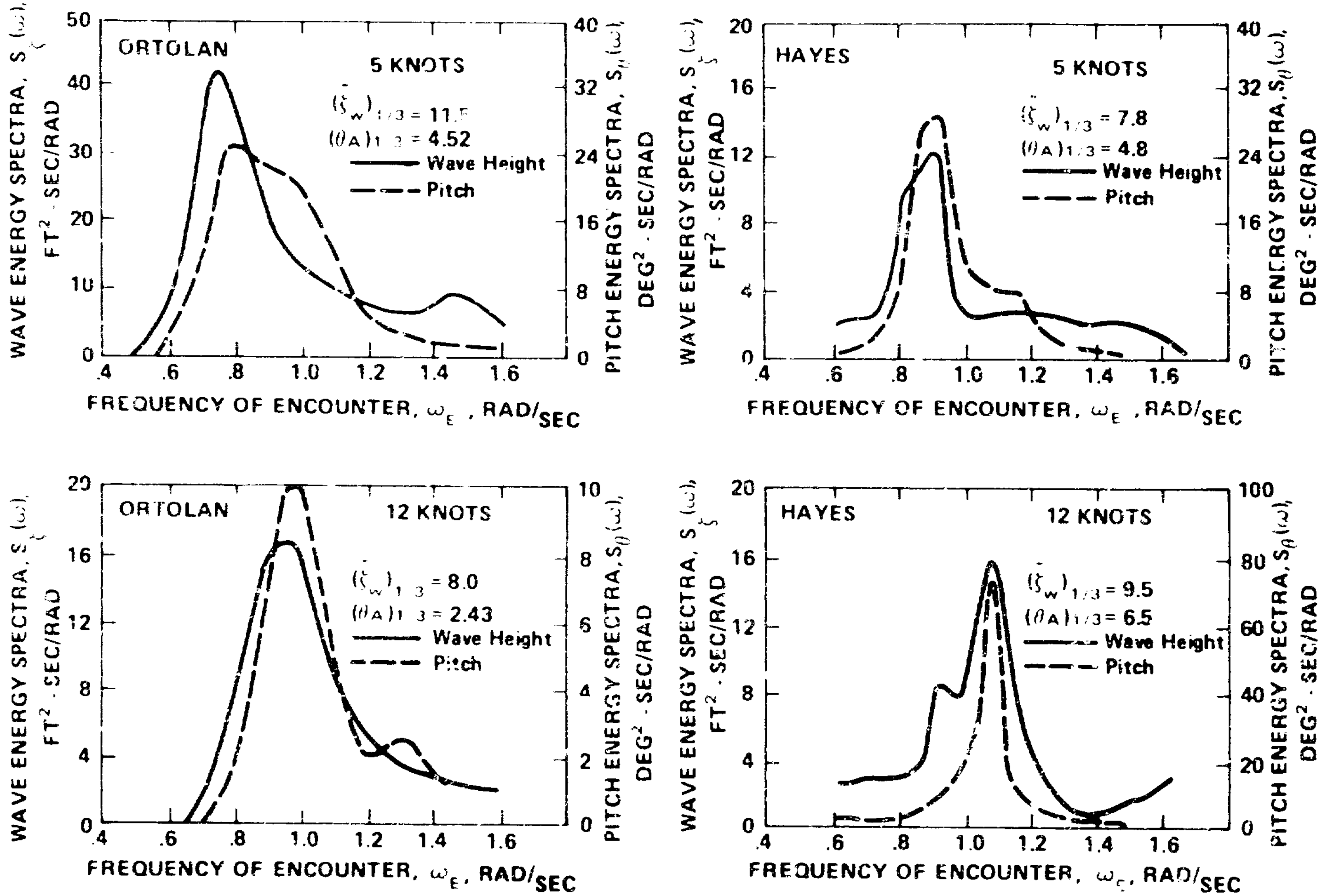

Figure 14 - Comparison Between ASR and AGOR-16 (USS HAYES) for Wave Height and Pitch Spectra in Head Seas

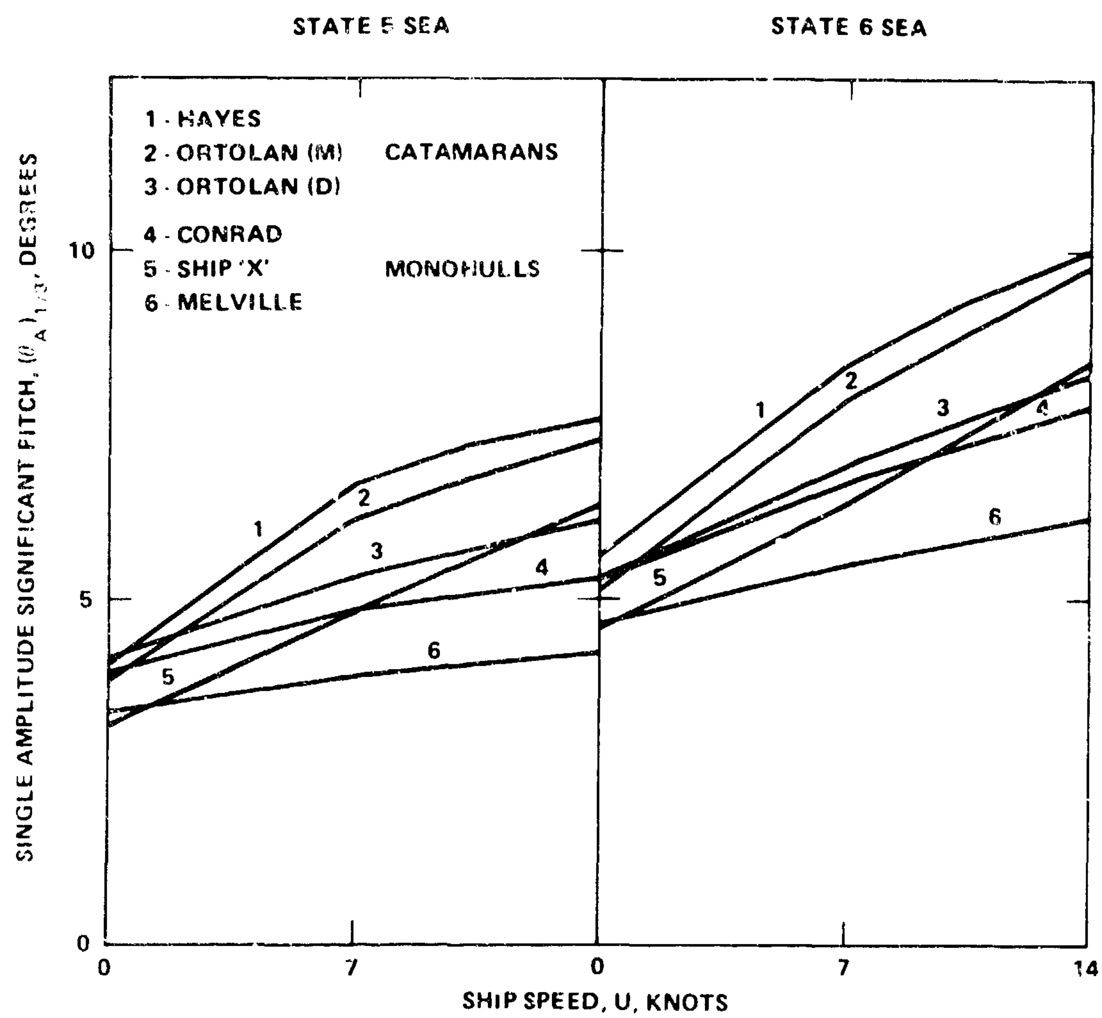

Figure 15 - Comparison of Pitch Angles versus Ship Speed in State 5 and 6 Head Seas

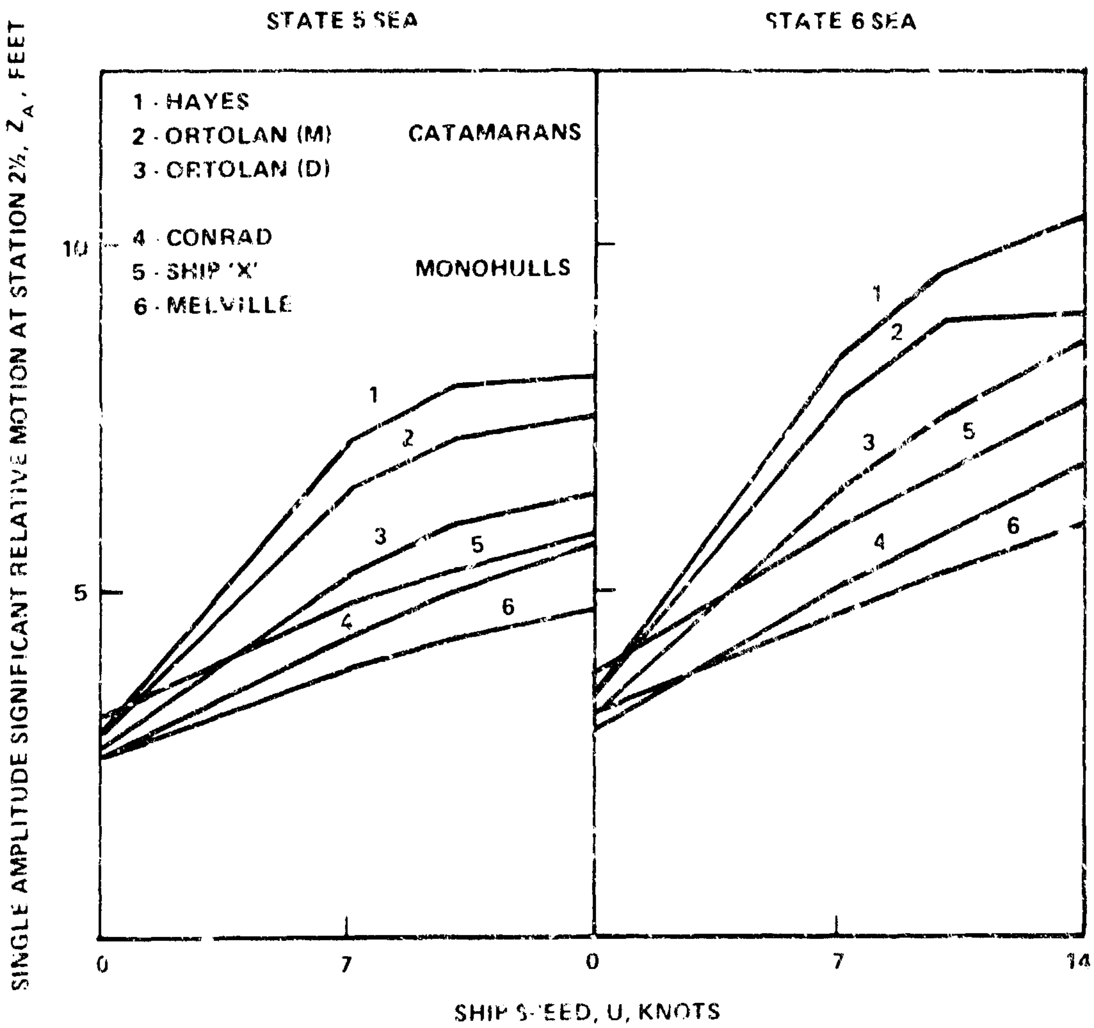

Figure 16 - Comparison of Relative Motion at Station 2½ versus Ship Speed in State 5 and 6 Head Seas

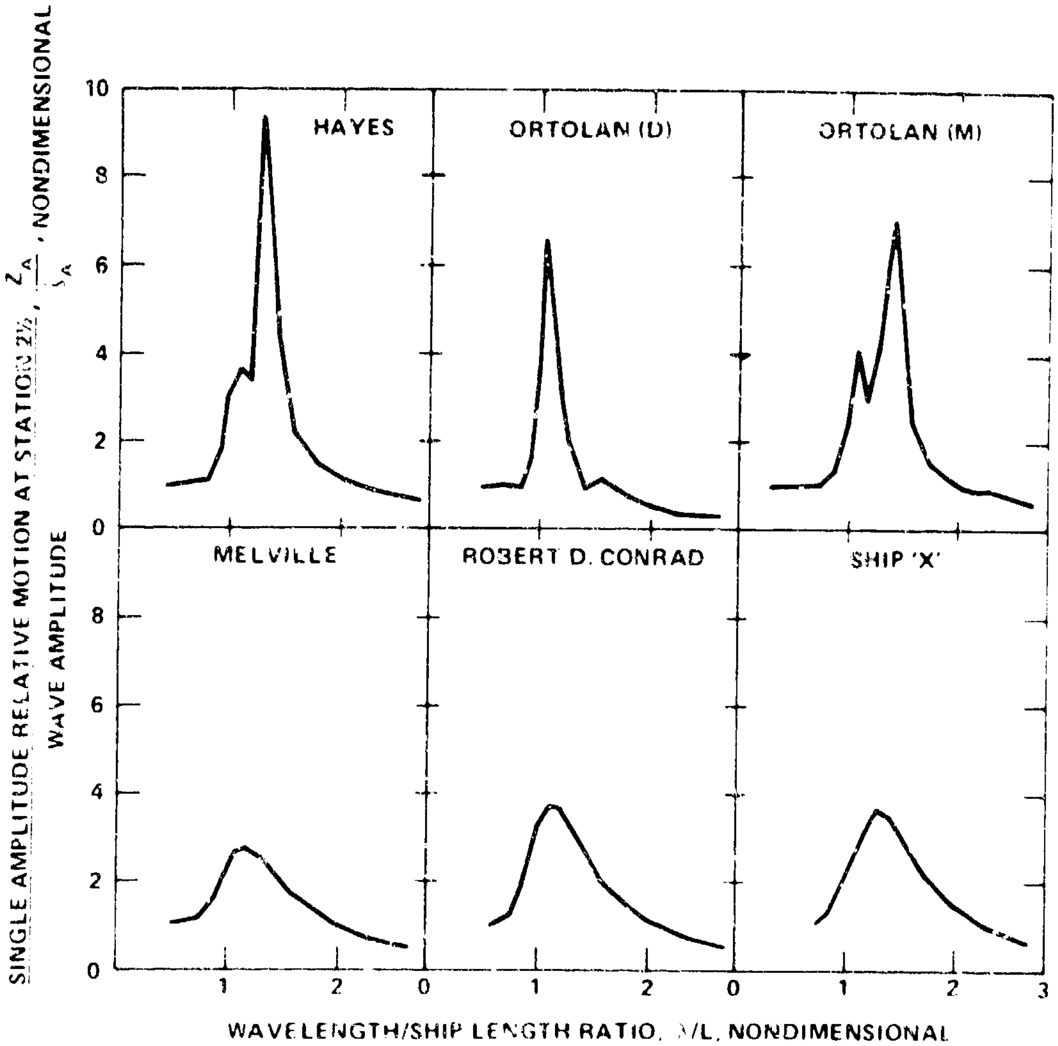

Figure 17 Nondimensional Relative Motion at Station 2½ versus Wavelength to Ship Length Ratio for a Ship Speed of 10 Knots in Head Seas

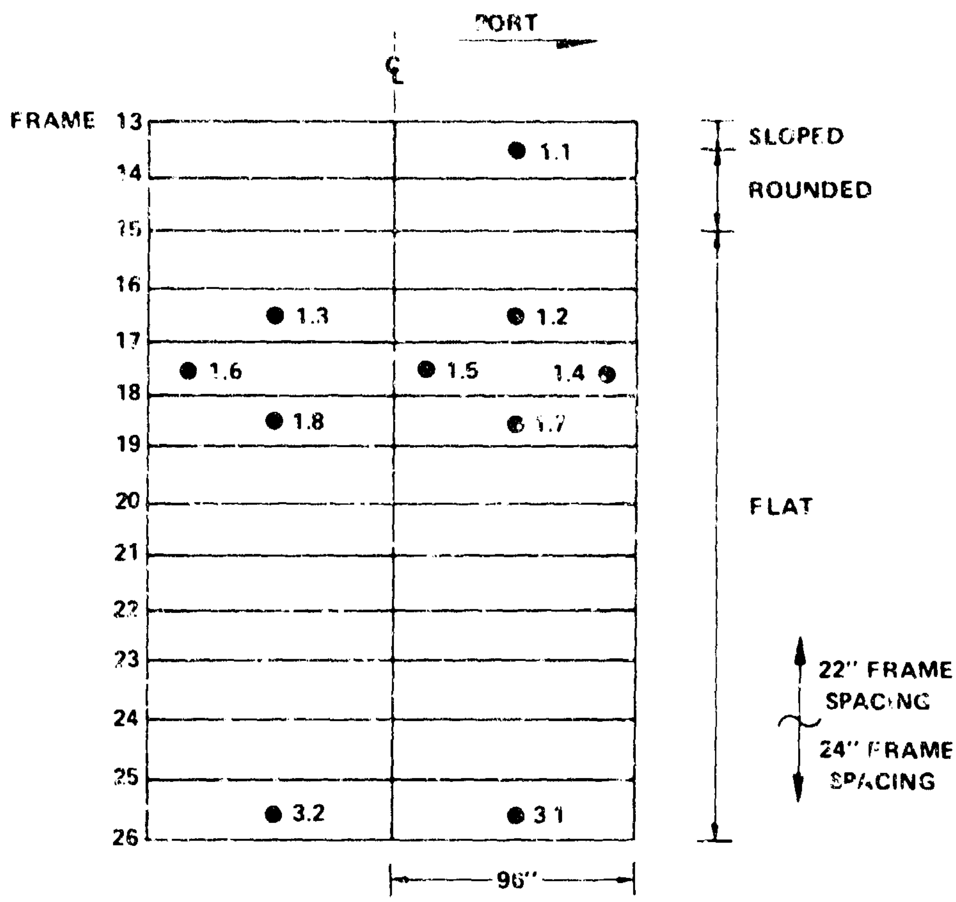

Figure 18 Pressure Gage Locations on Bottom of Forward Cross Structure; HAYES.